UNIVERSIDADE FEDERAL DO PARANÁ

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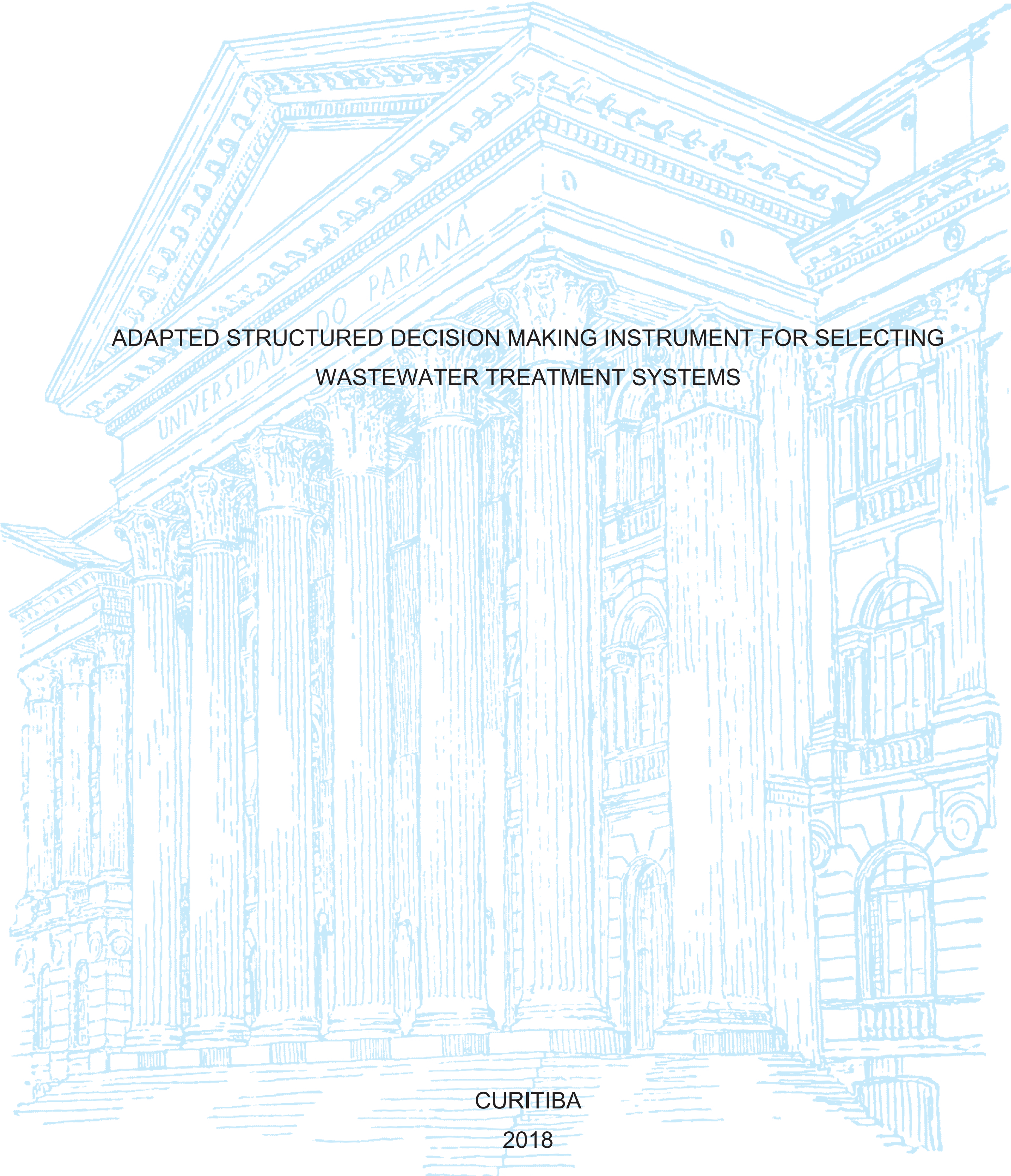

ADAPTED STRUCTURED DECISION MAKING INSTRUMENT FOR SELECTING WASTEWATER TREATMENT SYSTEMS

CURITIBA

2018

DANILO CESAR STRAPASSON

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Tese apresentada ao curso de Pós-Graduação em Engenharia de Recursos Hídricos e Ambiental, Setor de Tecnologia, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Doutor.

Orientador: Prof. Dr. Daniel Costa dos Santos

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TERMO DE APROVAÇÃO

Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em ENGENHARIA DE RECURSOS HÍDRICOS E AMBIENTAL da Universidade Federal do Paraná foram convocados para realizar a arguição da Tese de Doutorado de **DANILO CESAR STRAPASSON**, intitulada: **"ADAPTED STRUCTURED DECISION MAKING INSTRUMENT FOR SELECTING WASTEWATER TREATMENT SYSTEMS"**, após terem inquirido o aluno e realizado a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

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Curitiba, 09 de Novembro de 2018.

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RESUMO

Devido ao crescimento populacional e tendências de urbanização, áreas periurbanas que circundam as principais cidades estão aumentando de forma desordenada sem infraestrutura adequada de esgotamento sanitário, especialmente em países em desenvolvimento. Embora o referencial bibliográfico indique que existem estações de tratamento de esgoto (ETEs) convencionais e inovadores que poderiam convenientemente mitigar as questões citadas, um dos principais problemas reside no processo de escolha de uma alternativa adequada. Mais especificamente, em como recorrer ao uso adequado de instrumentos de análise a tomada de decisões (ATD) e suas ferramentas. Nesta abordagem, uma lacuna importante relacionada à temática é que as ferramentas disponíveis não consideram a integração de atributos como facilidade de uso e interatividade visual.

Portanto, esta pesquisa adapta, aplica e avalia um ATD estruturado, denominado Structured Decision Making (SDM), em um processo de decisão complexo para um cenário específico. Ademais, o estudo também desenvolve, aplica e avalia a ferramenta de pré-seleção de alternativas do WWTS (PS-WWTS), além de auxiliar no desenvolvimento e aplicação de outra ferramenta, o ValueCharts. Ademais, embora praticamente todas as ETEs inseridas no PS-WWTS sejam amplamente conhecidas em ferramentas similares, esta investigação também inclui o Sistema de Tratamento Ecologicamente Projetado (STEP) como uma alternativa descentralizada e sustentável, assumida como adequada para o cenário eleito. Os desempenhos relacionados aos indicadores definidos para o SDM foram obtidos a partir do referêncial bibliográfico. Ademais, no capítulo de Materiais e Métodos é abordada a estrutura do estudo de caso a uma análise comparativa de ETEs em um cenário real, dada a participação de diferentes grupos de participantes.

A sequência estabelecida da aplicação do referenciado instrumento (SDM) demonstrou coerência e, portanto, o processo foi considerado eficiente. Em relação as ferramentas específicas, o conjunto de ETEs pré-definidas da ferramenta PS-WWTS foi consistente ao referenciar-se a ETEs mais implementadas em cenários semelhantes. Posteriormente, a operação do ValueCharts também foi considerada eficaz. Considerando uma análise absoluta, a alternativa Lodo Ativado (LA) foi a mais preferida. Entretanto, esta ferramenta também demonstrou preferências distintas dos participantes, permitindo outros julgamentos. Por exemplo, as investigações com o grupo da comunidade sugerem que as alternativas mais adequadas do WWTS devem considerar alguns aspectos ocasionalmente negligenciados na ATD relacionada com ETEs. Especificamente, àqueles ligados ao bem-estar das comunidades vizinhas. Ou seja, o potencial de odor e o repasse de impostos. Assim, os resultados também mostraram que o STEP pode ser também uma alternativa adequada e viável para o cenário definido. Finalmente, a aplicação do estudo de caso ainda permitiu identificar melhorias de todo o instrumento (SDM) e suas ferramentas.

Resumindo, o que se destacou através do uso da combinação de estudo de caso e elicitação de especialistas foi que essa tese pôde fornecer evidências empíricas de que existem ferramentas adequadas que apoiam complexos sistemas de ATD, como por exemplo em abordagens ambientais. Simultaneamente, podem haver evidências de que ETEs alternativas que abordam aspectos de sustentabilidade e descentralização podem ser adequadas em cenários periurbanos.

Palavras chaves: Sistema de tratamento de esgoto. Ferramenta de suporte a tomada de decisão. Tratamento sustentável e decentralizado.

ABSTRACT

Due to the population growth and urbanization trend, peri-urban areas that surround major cities are haphazardly increasing without proper sanitary sewerage (SS) systems in the developing world. Even though the literature review points out that there are conventional and innovative wastewater treatment systems (WWTS) which could conveniently mitigate the cited issues, one of the main problems lies on the process of choosing a suitable alternative, more specifically, in how to adequately resort to decision making analysis (DMA) and tools to support the definition of solutions. In this view, an important obstacle is that tools available have not considered the integration of attributes such as user-friendliness and visual interactivity.

Therefore, this research adapts and applies a well-structured DMA, namely Structured Decision making (SDM), into a complex decision in a specific scenario. Additionally, as specific objectives, the study develops, applies and evaluates other tools for pre-selecting WWTS (PS-WWTS) alternatives, and afterwards performs the evaluation process (ValueCharts). Although all the set of well-known treatment systems of the PS-WWTS acknowledges those existing in similar tools, this investigation also includes the Ecologically Engineered Treatment System (EETS) as a decentralized and sustainable alternative, assumed as suitable for the scenario selected. The performances correlated with the defined indicators were obtained from the academic literature. Moreover, Material and Methods presents an applied study into a real scenario in order to perform the comparison analysis, given the participation of different groups of participants.

The adapted SDM instrument was efficiently applied as depicted in this study. The established sequence has demonstrated coherence and thus the analysis has flowed adequately. Turning to the specific tools' analysis, firstly, the obtained set of WWTS alternatives from the PS-WWTS tool was consistent given the most applicable ones into similar scenarios. Subsequently, the ValueCharts tool operation was worthwhile to be applied in complex evaluations. Conclusively, the Activated Sludge Process (ASP) was the highest scoring alternative from the application of the tool considering absolute analysis. But rather specific, the Valuecharts tool has uncomplicately demonstrated distinct preferences from the participants, allowing the assessment of other possible judgments. For instance, the inquiries with the community group have suggested that most suitable WWTS alternatives should consider some aspects occasionally neglected in decision making analysis related to WWTS. In particular, those connected to the well-being of the nearby communities, i.e. – odor potential and pass-through taxes. Hence, the average results have also shown that the EETS might also be a suitable and a reliable alternative for the scenario selected. Finally, the applied study has permitted to identify improvements of the whole SDM instrument and tools.

Summing up, what has mostly standed out by using a combination of applied study and experts elicitation was that this thesis could provide empirical evidence that there are adequate tools that support complex DMA, for instance in the environmental fields. Simultaneously, there might be evidence that sustainable and decentralized WWTS alternatives can be suitable to the peri-urban scenario.

Key-words: Wastewater treatment systems; Decision making support tool;
Sustainable and decentralized treatment technologies.

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LIST OF ABBREVIATIONS AND SYMBOLS

A	Area (m^2)
ASP	Activated Sludge Process
BOD	Five-day biological oxygen demand (mg/L)
BSM	Benchmarking Simulation Model
COD	Chemical oxygen demand (mg/L)
DMA	Decision making analysis
EETS	Ecologic Engineered Treatment Systems
FC	Fecal coliforms (FC/100mL)
ISF	Improved sanitation facilities
MCDA	Multi criteria decision analysis
MLSS	Mixed liquor suspended solids
NH_3-N	Ammonia concentration (mg/L)
O&M	Operation and maintenance
PS-WWTS	Pre-selection of WWTS
SDM	Structured Decision Making
SS	Sanitary sewerage
TN	Total nitrogen (mg/L)
TP	Total phosphorus (mg/L)
TSS	Total suspended solids (mg/L)
UASB	Upflow Anaerobic Sludge Blanket
UBC	University of British Columbia
UN	United Nations
UNICEF	United Nations Children's Emergency Fund
WHO	World Health Organization
WSP	Waste Stabilization Pond
WWTS	Wastewater treatment system

CONTENTS

1 INTRODUCTION

1.1 RESEARCH CONTEXT

Sewerage network and drainage systems have a long history and examples were found in various ancient cultures. According to Wiesmann *et al*. (2007) the earliest and widely known wastewater network systems emerged in Mohenjo-Daro near the river Indus (Pakistan) in about 1500 BC. Others were built in 800 BC in Rome, and from 300 BC to 500 AD by the Ancient Greeks, when public latrines which drained wastewater into sewers and hence conveyed sewage and stormwater to collection basins outside the city (HENZE *et al*., 2008). It has not only aimed to convey both human excreta and stormwater as far as possible from urban territories, but rather to control odor and diseases.

Considering the European population increase, and therefore the associated sewage generation growth and inherent lack of sanitary sewerage (SS) systems, the creation of solutions that could provide adequate treatment and disposal of wastewater have become completely necessary. Interestingly, it seems to have been dormant, and traditional Wastewater Treatment Systems (WWTS) were not implemented on a broader scale until the late 19th century and early 20th, when the western cities started to install centralized sewer systems (PATERSON *et al.*, 2007).

Even so, many rivers throughout the world are still receiving large amounts of pollution either by insufficient or nonexistent treatment process of wastewater. The UN (2015a), WHO/UNICEF (2015) and WBG (2016) reports that discharging these hazardous compounds into the environment is a current phenomenon in the developing countries, hence the contamination of natural resources, and also the effect on human health, remain to be an important global ecological concern.

Following the preceding pattern, the causes for the cited health and correlated SS issues may be related to demographic trends (i.e. urbanization) of the 21st century, with rapid increase of both water consumption and sewage generation. In particular in the developing world, urban growth is faster and more haphazard than in the richest countries, and hence a large portion of the population lives in illegal or semi-legal areas. It often emerges in underserved or also commonly called peri-urban areas that lack provision of basic needs and planning (PARKINSON; TAYLER, 2003; MARA, 2003).

Although there is little detailed information available regarding wastewater management and mapping coverage worldwide, where only 55 countries have presented complete data (ANDERSSON *et al.*, 2016), the World Health Organization (WHO/UNICEF, 2017) estimates that, in particular in regions such as Sub-Saharan Africa and South Asia, approximately 30% of the world's population (around 2.3 billion people) lack access to Improved Sanitation Facilities (ISF). Martinez *et al.* (2008) and WHO/UNICEF (2017) discuss the meaning of the term ISF which denotes the separation of human excreta from human contact by mechanisms such as private or public toilet.

In this view, improving the access to the population and adequate conveyance for SS systems is one of the important challenges in several cities in other parts of the world, such as Latin American countries. Still, according to the WWAP (2017) report, a major priority in the case of Latin American cities is to build formal institutional capacity to manage water resources. The second is to solidify the progress achieved in SS by concentrating efforts, especially with regards to household connection and sustainable practices, in order to obtain universal service coverage by the year 2035. The UN-Agenda 2030 (UN, 2015b) fortifies these expectations when it establishes that it must be a priority to concentrate the efforts for those in vulnerable situations to provide the access to adequate SS systems for people all over the world by the year 2030.

In the case of Brazil, for example, as well as in other developing countries (MILLINGTON, 2012; KOOP; VAN LEEUWEN, 2016), it is frequent that communities far away from urban centers are the most underprivileged and hence least favored by municipal infrastructure. However, it is a challenging prospect since it is clear that the governments do not fund SS treatment systems in the same way that they provide other services, such as adequate healthcare or transportation, for instance.

To illustrate this point, the Metropolitan Region of São Paulo, which is one of the most important cities in Brazil, grew to approximately 9 times its size in the last 60 years, and most of its population lives in urbanized areas (IBGE, 2010a). According to the UN (2015a), the urbanization trend will continue in both developing and developed countries at least for the next 30 years, when it will be expected that at minimum 67% of the world’s population will be urban. Whereas urban centers produce high rates of wastewater, they are becoming dependent on lands where infrastructure within the SS context, in particular WWTS (KOOP; VAN LEEUWEN, 2016), could be installed.

1.2 CONTEXTUALIZING THE MAIN RESEARCH CONCEPTS

Turning now to the technical subjects further discussed in this research, traditionally, the word sanitation is generally associated with potable water supply and presence of sanitary facilities that provide adequate disposal of human excreta, as well as the reduction of pathogens in the environment in order to protect human health and improve life expectancy (WHO/UNICEF, 2015; WBG, 2016).

Nonetheless, the term sanitation (as in the case of Brazil's literature) can also involve aspects related to solid, liquid and gaseous waste managing, urban drainage and urban clean up, and finally, to control and promote the sanitary discipline of the soil use. In this view, Brazil (2004) defines sanitation as a set of socioeconomics actions to achieve the environmental salubrity. Another valuable definition of sanitation was given by PROSAB (2009), stating that one of its main purpose is to promote hygiene and health to the population, while it is also pointed out as the greatest medical advance of all time.

Along the same lines, sanitation can be summarized as a set of measures for environmental control, and according to Mara *et al*. (2010), adequate sanitation, hygiene, and potable water are essential elements to a good public health and a social and economic development of a community. Lennartsson *et al.* (2009, p. 1) corroborate those statements by highlighting that "environmental protection, especially with respect to water, is not a luxury but a prerequisite for a well-functioning society".

Additionally, 15% of the total population, who represent 1.1 billion people, defecate directly on the soil (UN, 2015a), where pit latrine "system" is predominant (KATUKIZA *et al.*, 2012), even though it is widely known that it does not prevent the contamination of the groundwater. Over two million people die every year from diseases associated with the lack of SS and hygiene (WHO/UNICEF, 2000; LANGERGRABER; MUELLEGGER, 2005; WHO/UNICEF, 2015). These rates demonstrate an important issue taking place around the world, which requires immediate, fast and affordable solutions related to SS systems.

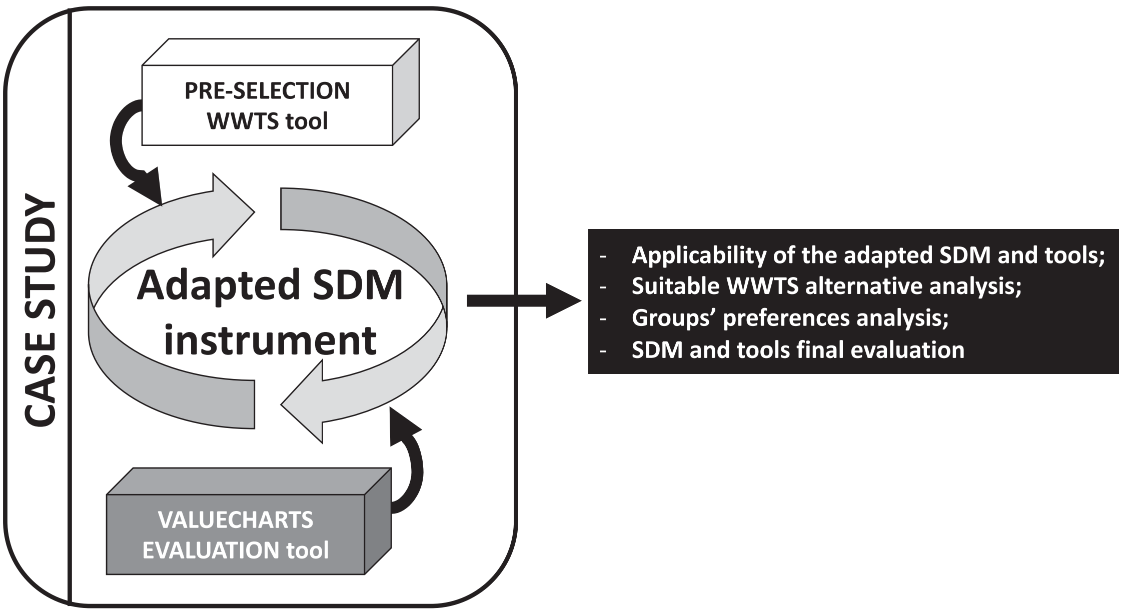
Since SS systems involve both conveying and treatment mechanisms, the abbreviation WWTS is going to be related exclusively to the treatment of SS in this research. Thus, one expected result is to select the most suitable WWTS into a specific scenario by using principles of Structured Decision Making (SDM). This is one of the many decision making analysis (DMA) processes to support collaborative and participatory generic decisions in the field of environmental engineering (GREGORY *et al.*, 2012).

1.3 RESEARCH GENERAL DESIGN

To apply the adapted SDM in this research, the procedures described by Gregory *et al.* (2012) were followed considering these three steps: i) the contextualization of the problem and the definition of the participants; ii) the discussion of the representative indicators and possible alternatives; and finally, iii) the evaluation criteria.

In this view, Figure 1 briefly introduces the overview of this study, wherein tools were included to support the whole analysis.

FIGURE 1 – RESEARCH'S SCOPE



SOURCE: The author (2017).

Moreover, this research can be considered as an interdisciplinary study since it approaches on one hand the technical assessment while it performs a quantitative investigation about WWTS analysis. On the other hand, the applied SDM process also involves a qualitative examination since it seeks to evaluate the preferences and opinions of different groups of participants. In other words, this second approach contemplates a more humanistic perception. It is therefore expected that the chosen decision making process considers some specific characteristics and make this study helpful towards the problematic dissertated.

1.4 OVERVIEW OF THE ENGINEERING AND PROBLEMATIC CONCERNS

Considering the lack of wastewater management in the developing world, it is notorious that underserved urban areas need to have measures to address treatment systems. Raw sewage has been straightly dumped in watercourses, and hence it is the cause of many different environmental issues. In other words, ecosystems have been damaged in different ways. In particular, in flora and fauna living decay and infectious diseases spreading.

It is also well known that SS flows are higher in urban areas than in rural and peri-urban areas (LALL *et al*., 2008; PALANIAPPAN *et al*. 2008; SCHOUTEN; MATHENGE, 2010; WWAP, 2017). However, Nogueira *et al*. (2009) state that the majority of the large-scale problems are usually being addressed, and the main challenge is to provide wastewater treatment to communities located beyond urbanized areas, for instance peri-urban and rural areas.

On one hand, Nogueira *et al.* (2009) also imply that due to the low rates of the SS coverage, specifically in metro areas that surround large urban centers, the adoption of technologies that acknowledge principles of decentralization and sustainability have also become necessary.

On the other hand, given that there are available WWTS alternatives that incorporate those principles worldwide, the discussion is now turning to the top of the chain of water governance concerns. It has been widely argued that in many cases the causes are related to excessive costs and principally inadequate public policies. Thereby, recognizing water management in terms of using DMA process, as well as appropriate tools that incorporate specific features, might mitigate those issues.

According to von Sperling and Chernicharo (2005, p. 165), managing the implementation of WWTS should address the following steps:

- environmental impact studies on the receiving body;
- treatment objectives;
- treatment level and removal efficiencies.

In order to achieve these cited goals, many researchers have been proposing different approaches within the DMA concept in the field of wastewater management into distinct scenarios. As acknowledged in this study, the interdisciplinary analysis has employed an adaption of a specific DMA process to thereafter evaluate the most suitable WWTS alternative. It intends to contribute to the whole process by assessing and testing specific features related to the tools, within the DMA.

Firstly, in the view of using a DMA process for defining the most suitable WWTS for a specific scenario, it is highly recommended that a person, or a group of persons, manage the DMA.

Subsequently, it is important to summarize and highlight the common, and widely well-known, engineering steps to address the definition of WWTS for a general community. They are acknowledged in the SDM (GREGORY *et al*., 2012), which consist in the following steps:

- To define and aknowledge the extension of the problematic scenario and treatment expectations. It is necessary to collect data regarding the number of people who need to be favored by WWTS facilities, the population density, and the wastewater characteristics;
- To define the indicators;
- To choose available technologies that can fit on that specific scenario.
- To establish its performances;
- To evaluate the pre-chosen alternative by using appropriate decision making process, and based on the decision-makers' preferences.
- Finally, to control and evaluate the whole project.

One of the most important stage within the first step is to characterize a relevant group of participants to perform the process. In this view, Marttunen *et al.* (2015) argued that environmental issues commonly concern a variety of participants with different needs and perspectives about the environment. Additionally, Chamberlain *et al.* (2014) points out that an adequate DMA process should consider aspects of participation, transparency and comprehensibility of all the people involved. It certainly reflects on more participation of all participants in the process of choosing and designing solutions.

Summing up the first step, the managers of the DMA are therefore responsible for gathering the information delineated at the first step. In light of this view, the selected DMA process of this research (namely SDM) involves other several different groups of participants (e.g. watershed and sanitation specialists, government representativeness and needed community).

Secondly, seeking the need of providing solutions that mitigate the issue of lack of SS systems in haphazard urbanization scenarios, it is well known that the indicators should consider the "triple bottom line", or "three pillars" of sustainable approaches, that is the balance of distinct indicators related to the main aspects: economic, social and environmental (MUGA; MIHELCIC; 2008, MOLINOS-SENANTE, 2014). Palaniappan *et al*. (2008) corroborate to this argument by stating that to address correctly the issue of lacking access to SS systems, it is necessary that the technologies contemplate economic, ecological and social approaches, and in addition, also to look at natural practices (as discussed in subsection 3.2.7) in their processes.

In the third step, the managers need to go through tangible and available alternatives. Thus, a tool for pre-selecting wastewater treatment systems (PS-WWTS) was developed, applied and evaluated, wherein conventional and widely well-known WWTS alternatives were considered as well as another one, the so-called Ecologically Engineered Treatment System (EETS).

The fourth step can be summarized as the compilation of the performances of the pre-selected WWTS alternatives. Despite the fact that there are diverse techniques for data collection, this research has considered literature review, which is further detailed.

Once the manager has advanced the four previous steps, in the fifth they are already able to select the most suitable WWTS alternative into a given scenario. In other words, a selected treatment system should hypothetically receive higher preferences from the participants of the DMA. As the name suggests, DMA processes, or so-called consensus-based analysis, are those that focus on the endpoint of bringing a group to a consensus agreement. Given these conditions, it is expected that the outcomes from the application of a whole DMA process can indirectly result in improvements in the public health and quality of life for vulnerable populations.

Recently, several researchers have used computer tools that include principles of DMA, as mentioned by Kalbar *et al*. (2012). ValueCharts tool is the one focused on the evaluation process in this research, which was created considering user-friendliness and visual interaction features.

Finally, in order to reach those aims, this study has completely contemplated the first five engineering concerns (i.e. SDM process) previously cited in this section. Unfortunately, the last one (evaluating and controlling) was not able to be integrally performed given the lack of time and resources. In this view, the original evaluating process was adapted to a short analysis of the obtained results and of the main steps of the process.

Nonetheless, it certainly brings some improvements in the subject approached. That is due to the fact that the outcomes support and facilitate the decisions that go in direction of the restoration and resilience of watercourses in terms of quality and conservation, as well as the whole ecosystem's health. Additionally, but not less important, the prevention of future deterioration of the ecosystem without excluding the consideration of social aspects with regards to the population's wellness.

1.5 RESEARCH RELEVANCY

In the view of the human perception, this research intends to contribute to support the decision making process related to providing SS infrastructure for specific communities. It is going to be achieved by proposing an adapted SDM instrument that contemplates tangible and well depicted steps easily operated by both managers and users. The incorporated tool's features within the instrument were also tested in terms of, for example, being user-friendly and considering visual interaction. More interestingly, it is expected that the manager of the decision making process and the users can conveniently state their preferences, according to the scenario selected and its characteristics.

Regarding the WWTS approaches, this research has proposed a sustainable and decentralized treatment configuration. In this view, the EETS was found as a suitable alternative to specific non-urbanized scenarios in developed countries. Hence, it was evaluated in terms of whether it incorporates or not those cited attributes to be further selected within the scenario defined.

Finally, it also presents innovative characteristics since it does not only evaluate distinct techniques to treat domestic sewage by simply using principles of DMA. It firstly proposes a pre-selection tool of WWTS alternatives, and additionally the ValueCharts for the evaluating process. Continuing to approach the innovating aspect, this research intends to support sufficiently, fairly and reliably the DMA contextualized here. Those attributes were achieved given the number of possible WWTS's configurations, alternatives and indicators, and due to the intrinsic tool's features.

1.6 RESEARCH QUESTION

The following research intends to answer the question: Can an adapted DMA instrument, namely SDM, which incorporates useful tools with specific attributes (e.g., user-friendliness, visualization and interactiveness), support the definition of suitable WWTS alternatives and ensure water-hazard resilient infrastructure?

1.7 HYPOTHESES

As seen in Table 1, it is shown the behavioral approaches of the hypotheses related to the application of both applied SDM instrument and internal tools of this study, in which the reliability of the stated participants' preferences is also assessed.

TABLE 1 – BEHAVIORAL APPROACHES REGARDING THE DECISION MAKING TOOLS

	H_0: Null Hypotheses	**H_1: Alternative Hypotheses**
SDM Instrument and tools usability	Complex decision content requires advanced background of the user and complex instruments and tools	Complex decision content does not require theoretical user background and complex instruments and tools
	Visual and interactiveness features are strong motivations for using decision making tools	Non-visual or interactiveness are strong motivations
Specialists Group	Heavily biased in the environmental group of indicators	Non or uncertainly biased in specific group of indicators
	The participation in the DMA is relevant	Neutral relevancy in the DMA final outcomes
Community Group	Heavily biased in social group of indicators	Non or uncertainly biased in specific group of indicators
	The participation in the DMA is neutral or irrelevant	The participation in the DMA is relevant
Government Group	Heavily biased in economic group of indicators	Non or uncertainly biased in specific group of indicators
	The participation in the DMA is relevant	Neutral relevancy in the DMA final outcomes

NOTE: DMA – Decision Maing Analysis
SOURCE: The author (2018)

The null and alternative hypotheses referred in Table 1 are concerned with theoretical approaches. In other words, they were defined from general statement hypotheses, which tested the behavior of the participants who participated in the analysis.

1.8 STRUCTURE OF THE RESEARCH

This research was divided in six chapters. Table 2 summarizes the structure and main subjects of each.

TABLE 2 – RESEARCH'S STRUCTURE

Chapter	Title	Main subjects
1	Introduction	To briefly introduce the main research aspects. For instance, the engineering concerns followed by the research relevancy, subsequently the research question and finally the hyphoteses were also highlighted.
2	Objectives	To define the objectives of this research based on the gaps examined in the introduction.
3	Literature Review	To give descriptions of the main references that support the theoretical foundation and the ambitions of this thesis. In other words, the bibliographic references were developed, to consolidate the background with respect to the concepts of urbanization trends, sewerage treatment systems and the DMA processes (also their tools).
4	Material and Methods	To present the material and methods structure. It includes the strategy of the construction of the SDM instrument and its tools to achieve the goals. Finally, the explanation for the applied study that makes part of the adapted SDM process.
5	Results and Discussion	To describe the results concerning the application of the materials and methods. The results analysis and discussion chapter mainly intends to demonstrate the applicability of the instrument and tools and test the hypotheses.
6	Conclusion	To present the conclusions after the application of the material and methods and the analysis of the obtained results. Additionally, limitations of this study as well as suggestions for further researches were also discussed and recognized.

SOURCE: The author (2018)

2 OBJECTIVES

The overall goal of this research is to develop, apply and analyse the adapted Structured Decision Making (SDM) instrument using tools – the Pre-Selection Wastewater Treatment System (PS-WWTS) and ValueCharts, in order to select the most suitable WWTS alternative into a specific scenario.

2.1 SPECIFIC OBJECTIVES

The specific objectives are:

- To select the set of indicators further adopted within the decision making process.
- To elaborate and analyse the PS-WWTS tool, which aims to define a limited number of pre-alternatives resorted into the adapted SDM process;
- To experiment the Ecologically Engineered Treatment System (EETS) as a suitable alternative for the specific scenario selected;
- To define all associated performances' data of those pre-defined systems through an accurate examination within the literature review;
- To propose a feasible and suitable WWTS alternative, or more than one, to the selected scenario.

3 LITERATURE REVIEW

Supporting the aims of this study, the overall content of urbanization and its relations with poor Sanitary Sewerage (SS) systems worldwide are firstly and briefly presented. Afterwards, the concepts of conventional ones and a specific sustainable and decentralized WWTS were described. Finally, the subject of Decision Making Processes (DMA) and the tools that usually support them are depicted and discussed.

Thus, Section 3.1 seeks to provide the background of some essential issues related to the lack of SS systems in terms of urbanization trends. In other words, it intends to discuss the following questions:

- What are the problems involved, and hence the probable causes related to poor coverage of SS systems?
- Are there any recent studies that discuss solutions?

This section concludes aiming at the pattern of urbanization by focusing on its causes and consequences in the field of SS systems. It concerns the rapid and haphazard household settlement, in particular in the developing world, and its consequences connected to public health.

Thereafter, Section 3.2 includes subsections presenting approaches related to SS systems and rather specifically with respect to WWTS approaches. Subsequently, the most commonly used WWTS in developing countries, as well as the modern concepts of sustainable systems with extra attention to the Ecologically Engineered Treatment System (EETS) are also advanced.

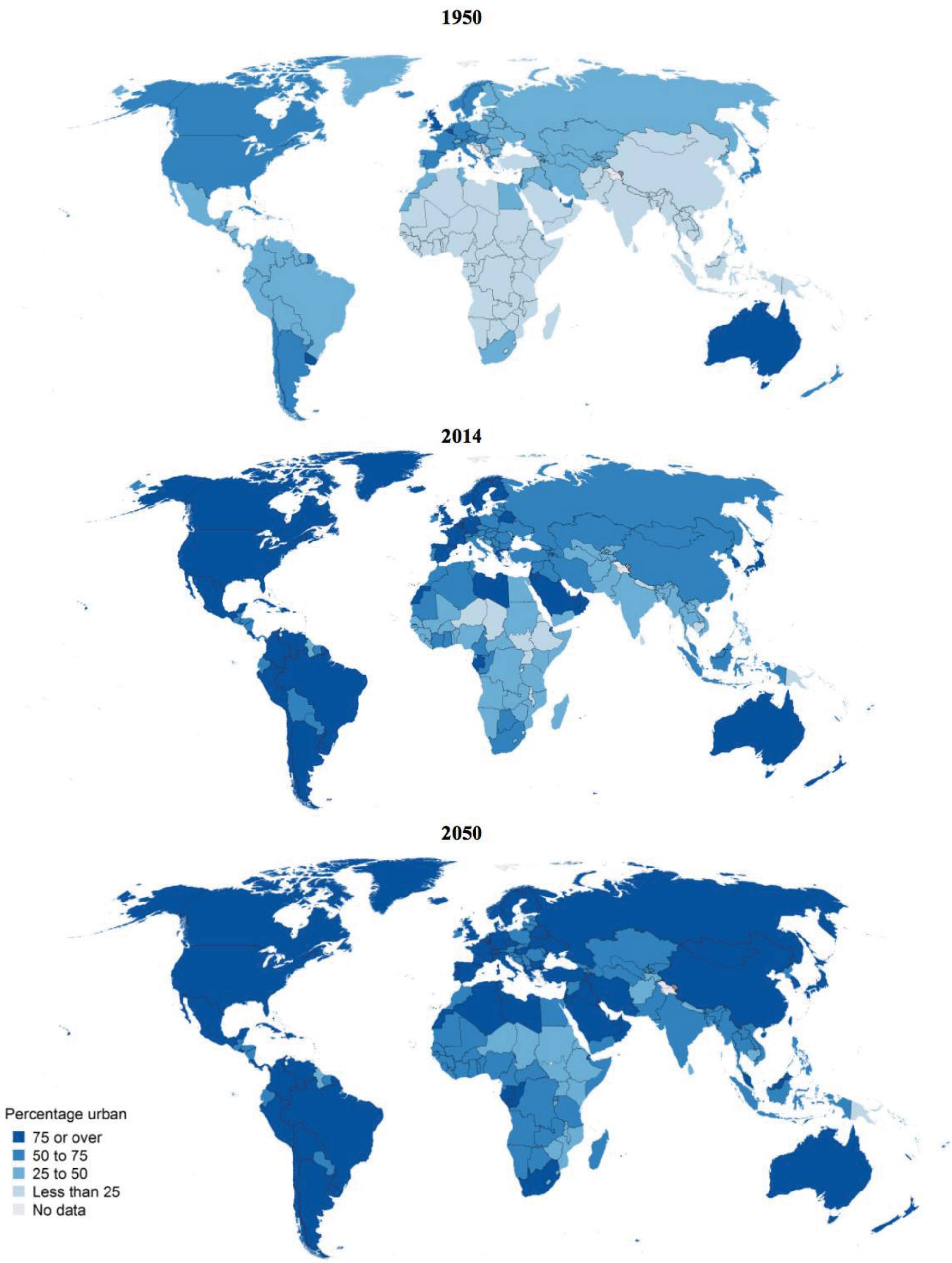
Section 3.3 presents general aspects of DMA, specifically with regards to the steps that need to be followed in order to provide the basic understanding, considering analysis with multiple indicators and alternative attributes. Additionally, it presents variations of computer tools used worldwide in this field, with emphasis on the ValueCharts tool that is adopted as part (evaluation step) of the applied study.

Finally, Section 3.4 discusses the blank gaps in the thematic presented within all the literature review, especially those that are directly related to the proposed objectives.

3.1 URBANIZATION: TRENDS AND THE RELATION WITH PUBLIC HEALTH

Due to the industrial revolution and the rapid economic growth beheld in the end of the nineteenth century and beginning of the twentieth century, the rapid process of urbanization in Europe and Northern America (UN, 2015a) was observed. Figure 2 corroborates that this trend is still valid, also showing the urban progression worldwide from the middle of the 20th century and an estimative for 2050.

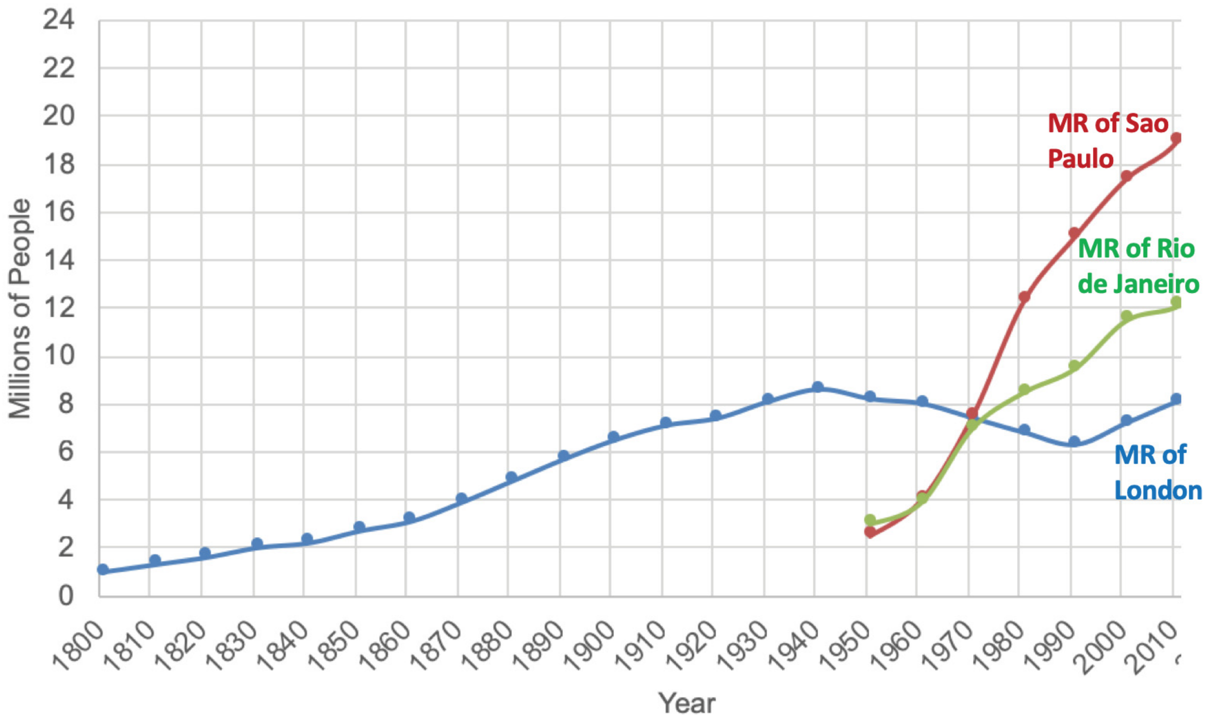
FIGURE 2 – PERCENTAGE OVER TIME OF POPULATION RESIDING IN URBAN AREAS WORLDWIDE



SOURCE: UN (2015a)

Still, recent researches recognize the trend for urban centers to increase even more in many developing countries, such as in Latin America and Caribbean regions (UN, 2015a; KOOP; VAN LEEUWEN, 2016). The data described in Figure 3 demonstrate that it is highly complex to compare the patterns of urbanization in important cities which belong to low and high-income countries.

FIGURE 3 – POUPULATION OF METROPOLITAN REGIONS (MR) OF LONDON, SÃO PAULO AND RIO DE JANEIRO



SOURCE: Adapted from IBGE (2010a) and Financial Times (2016)

As shown in Figure 3, metro areas of London took two hundred years to grow from 1 to 8 million inhabitants, while Rio de Janeiro and its metro areas grew approximately from 3 to 12 million people in just sixty years. Additionally, Metropolitan Regions of Sao Paulo increased its population from 2 to 19 million within the same period of time as Rio.

In light of this context, indiscriminate and contemporary population are increasing within, and rather around the main cities in the developing countries. Konteh (2009) has advocated that these nations have observed this rapid and haphazard urban growth, which has resulted in settlements without satisfactory access to basic needs, such as social, environmental and health services. In addition, Rana (2009) states that in Bangladesh the formation of slums without adequate public services related to SS systems extensively contributes to a hazardous environmental condition.

Notably, those problems mentioned have been observed mainly in the surrounding areas of urban centers, where there are no proper planning nor coverage of sewage systems for all the population. Indeed, Lall *et al*. (2008) and Martinez *et al.* (2008) endorse this statement by arguing that it is easily perceptible the inefficient land use in peripheral or marginal areas, which is one of the most important causes of the origin of slum and squatter settlement.

Schouten and Mathenge (2010) also add to this context by indicating the mushrooming of irregular settlements, and that “policy makers seem not to be willing and able to serve”. In WWAP (2017), those statements are also corroborated when it is advocated that "the number of people without access to water and SS systems is directly related to the rapid growth of population in the peri-urban area in the developing world". This report also adds that the political inability factor in these countries (especially in sub-Saharan Africa and south Asia) can be the reason for the lack of basic infrastructure facilities, especially in terms of SS systems for needed populations. In other words, the population in particular from developing countries that resides encompassing urban centers are usually underprivileged in terms of basic infrastructure (LALL *et al*., 2008; SCHOUTEN; MATHENGE, 2010; WWAP, 2017).

Some notable data supports those mentioned about such worrying scenario by bringing information with respect to SS coverage. The WWAP (2017) estimates that only 20% of the discharged wastewater worldwide is properly treated. Additionally, even though 2.1 billion people have gained access to improved sanitation facilities, about the same amount still lack access to any type of SS infrastructure or equipment. The report also points out that when comparing treated sewage in relation to sewage produced by developed and low-income countries, the difference goes from ranges of 70 to 28%, respectively.

Moreover, although real conditions in extremely poor countries are even more precarious, the *Sistema Nacional de Informações sobre Saneamento* (SNIS, 2016) points out that Brazil also has an important deficit related to residents who do not have connection with the public sanitary sewerage systems near their homes.

Despite the increasing presence of sewerage network in Brazil between the years 1989 and 2008 (IBGE, 2011), only approximatly half of the Brazilian homes have any type of sewage collection, whereas only 74% of those have treatment (SNIS, 2016). The IBGE (2011) also states that the other portion of the households conducts their sewage into devices such as septic tanks and rudimentary (on-site systems), or directly discharged in soil and water bodies. It is also important to highlight from the SNIS (2016) report the discrepancy of sewage collection absence per domicile in different regions in Brazil.

On one hand, the SNIS (2016) report states that the North and Northeast regions of Brazil are those which present the lowest levels of access to sewage treatment networks (11.2 and 32.2%, respectively), followed by the South (54.7%) and Midwest (54.7%) regions, which also have inadequate levels of wastewater network coverage. On the other hand, the large coverage occurs in the Southeast region, where almost 82% of the residences have proper sewerage infrastructure. Even though the statistics seem to be quite higher to Southeast regions in comparison with other sectors in Brazil, the SNIS (2016) argues that only approximately 68% of this effluent is treated.

By scrutinizing the urban population in Brazil specifically, it could be found that 58% has access to sewerage network, and 74% of that is further treated (SNIS, 2016). However, by evaluating the total population, only 50.3% of the households have access to wastewater networks whereas only 42.7% is treated.

As reported by Schouten and Mathenge (2010) one of the important reasons for this lack is the low effort from the governants to improve those areas with basic needs systems, in particular sewage collection and treatment, and others such as urban drainage, potable water supply and generation of electric power. Additionally, as reported by Paraskevas *et al*. (2002), in the developing countries other reasons can be cited. For instance, reduced local budgets, disqualified employees, and lacking funding (PARASKEVAS *et al*., 2002). Massoud *et al*. (2009) corroborate these statements defending that the major barrier to implement those projects in the developing countries is related to the elevated costs of WWTS construction and management.

In light of this problematic scenario, entire communities which live in areas that lack appropriate sewerage and drainage systems frequently use nearby sources of fecal contaminated water bodies for cleaning, recreation and consuming (MARTINEZ *et al.*, 2008). Moreover, infectious diseases, and in so many times deaths, are frequently the consequences in those underserved urban areas. Mara *et al*. (2010) state that diarrhea is the cause of the death of approximately 2 million people worldwide annually, especially children in developing countries. In this view, UN (2015c) reports that ensuring proper SS systems (i.e., conveying, safe treatment and disposal of wastewater) directly reduce disease and healthcare expenses especially in the extreme poverty scenario. Additionally, the report highlights that those mitigation procedures related to providing SS also exponentially decrease deaths among children under five.

In addition, in consequence of the lack of basic infrastructure, the high pollution levels of the water bodies can be related to surface runoff and hence transport of pollutants. In other words, data from studies applied in China (CHEN *et al*, 2015) suggests that urban flooding caused by heavy rain is often the explanation for the occurrence of the process of washing surfaces and the accumulated pollutants, which are then conveyed into urban drainage systems. Repeatedly, it can be therefore understood that this issue is frequently a consequence of the unplanned urbanization, the growth of construction rate, impermeable areas and inadequate urban drainage planning. Finally, another important problem due to the limited SS infrastructure is associated with nutrients that are directly discharged into the water bodies, strongly intensifying the process of eutrophication (LIGTVOET *et al.*, 2014).

In order to provide a solution to these issues, Paterson *et al.* (2007) emphasize that conventional SS systems might not be the answer to the problem of low-income urban communities. On the contrary, there is a need for alternative solutions which need to be feasible and attractive to be implemented in underserved urban areas (SCHOUTEN; MATHENGE, 2010).

Regarding this point of view, Schouten and Mathenge (2010) concluded in their research that it is possible to enhance SS coverage into underserved urban areas by considering characteristics that shall contemplate technical and economical criteria. Louzada *et al.* (2013) also agreed with the necessity for changing the paradigm since they discuss that a solution would be the use of combined techniques such as optimization, modeling, and the creation of modular WWTS into those scenarios that lack basic needs.

Moreover, another important aspect in this context which has been lately considered in the literature review is related to decentralization approaches (HO; ANDA, 2006). In summary, the authors explain that the concept of decentralized WWTS means the distribution of the coverage of sewerage systems for a presumed number lower than 5.000 people. They also add that decentralization appears to be a low term solution to those peri-urban areas. Nevertheless, due to the fact that rapid and haphazard urbanization can turn low-density areas into high and immense density ones, on-site systems, which approach decentralized aspects, may not be the best solution since it increases the risk of contamination of the groundwater and hence the drinking water sources (PATERSON *et al*., 2007). The authors argued in terms of the difficulties to control the process of treatment of each unity, also regarding the poor drainage of the ground conditions.

Therefore, considering the impacts related to urbanization trends and ineffective SS around the globe, the following two sections were delineated mainly to provide an overall review with regards to both conventional and sustainable WWTS solutions, while the subsequent is related to decision making process and its intrinsic gaps. The final section aims to incorporate and review the discussion, elucidating the relations with the sought objectives.

3.2 WASTEWATER TREATMENT SYSTEMS

The WHO/UNICEF (2015) reports that wastewater infrastructure is formed by the collection and treatment process that respectively aim to convey the influent and transform it in a feasible effluent in order to be forward released in water bodies. In summary, the WWTS goals are the conservation of the environment and improvements on the quality of life of a community. Likewise, the efficiency of SS systems and the correct management of practices of waste will result in social benefits such as environmental conservation regarding pollution detention. Consequently, it improves the public health and productive potential of the population, hence the creation of jobs, and finally the dynamism of the economy.

In addition, SS (also called domestic sewage) is essentially proceeded from households, multi-family, residential condominiums, commercial buildings, amongst others, and more specifically from several and different types of devices (e.g. toilets, sinks and showers).

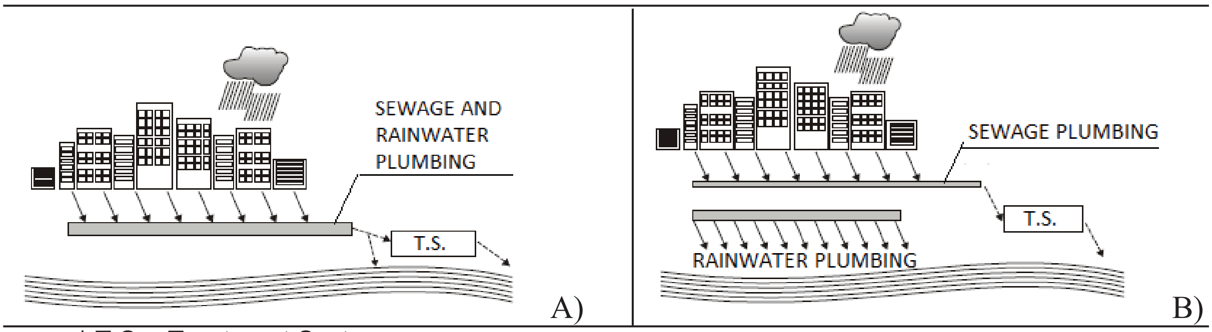
Moreover, the types of collection of sewage and treatment systems can be divided into two classifications, as illustrated by MetCalf and Eddy (2014). The first one is known as ‘unitary’ or ‘combined’ WWTS, and the following is called ‘absolute separation’ WWTS. The main details and features of these systems are presented in the next subsections.

3.2.1 Traditional Approaches of Collection and Conveyance of Wastewater

The traditional so-called 'linear and end-of-pipe' solution consists of flush-toilets, a piped sewer network and a central treatment facility where water is used to convey sewage from homes to the end-point. Then, sewage is discharged into an urban drainage system with or without treatment. The process of these systems may be 'unitary', or also called 'combined', which means that within the network there is also precipitation wastewater conveyed, or 'absolute separated' collection system, where sanitary wastewater and stormwater are conducted independently (METCALF; EDDY, 2014).

Regarding the concepts of unitary or combined systems (Figure 4 - A), the raw sewage and rainwater are conveyed within the same network pipes to the final destination. Likewise, the authors MetCalf and Eddy (2014) indicate that wastewater in combined systems is essentially composed of household and industrial waste and rainwater collected in urban drainage networks.

FIGURE 4 – (A) COMBINED COLLECTION SYSTEM CONVEYING PRECIPITATION (STORMWATER) AS WELL AS SEWAGE; (B) SEPARATE COLLECTION SYSTEM WHERE PRECIPITATION AND SEWAGE SOURCES ARE CONVEYED INTO TWO DIFFERENT NETWORKS



* T.S. - Treatment System

SOURCE: Adapted from MetCalf and Eddy (2014).

As reported by WWAP (2017) in old systems in Europe, such as some built in Paris for example, the original sewers were designed only for rainwater and greywater. However, as it has recently been broadcasted by some important news in Canada, such as Hutchinson (2016) and Nair (2016), this solution has been profusely discussed and seemed to be controversial in Victoria – BC, which has dumped its raw sewage into the ocean for decades. Combined systems also complicate treatment as the variable nature of precipitation causes variation in the sewage concentration and brings difficulties within the treatment process, which in almost all cases needs the properties of the raw sewage in order to be efficient. That is one of the most important reasons why the absolute separation systems are becoming increasingly common worldwide and adopted in both developed and developing nations (METCALF; EDDY, 2014).

In the absolute separate system (Figure 4 – B), stormwater and sanitary sewage (domestic and industrial) are conveyed in separate networks into the final destination (METCALF; EDDY, 2014). The main advantage of this concept is related to the permissibility of releasing stormwater into networks in nearby watercourses, which means that there are no requirements for important interventions, and thus the reduction of implementation costs.

Finally, there is a variation of the previous, and traditional, cited typologies of wastewater networks systems, named partially separate system. This system provides the connection of a portion of rainwater from buildings, such as from rooftops and courtyards, which is forward conveyed together within the domestic sewage networks.

3.2.2 Typologies of Sanitation Systems

There are two main groups which can define the typology of WWTS. They can be classified as centralized or decentralized, and the characterization is based on the amount of the population served by the system (HO; ANDA; 2006). In centralized typology scenarios, collection of sewage receptors occurs from several households, communities or even towns, where effluent is normally conveyed into WWTS in order to be forward treated.

Therefore, centralized systems have the characteristics of treating high amount of wastewater contributions, for instance, higher than the contribution of 5,000 people, or flowrates of more than 1,000,000 liters per day (HO; ANDA, 2006). Although centralized systems seem to be a trend in developed countries, there is an increasing propensity in the opposite direction concerning the developing world, where decentralized WWTS are becoming suitable solutions for the portion of the population that lack basic needs (LIBRALATO *et al*., 2012).

On the other hand, in terms of decentralized systems, there are currently several and different studies and classifications, even though they generally address to the same concept. Records of the US Environmental Protection Agency *apud* Libralato *et al.* (2012), which is corroborated by Ho and Anda (2006), classify small and decentralized plants as those that receive sewage from household not exceeding 5,000 people.

In this view, a generic and widely well-known conceptualization of decentralized systems is that these systems are capable to collect, treat and dispose the sewage from homes or small group of homes. Still, Libralato *et al.* (2012) add that centralized system in a community can be conveniently substituted for a set of decentralized systems. It agrees with the concepts stated by Ho and Anda (2006), without any absence of efficiency.

Illustrating this point, Massoud *et al*. (2009) presented a hypothetical study in a rural community scenario. They have demonstrated that in terms of capital and also operational & maintenance (O&M) costs, approximately 80% and 60%, respectively, can be economized by using principles of decentralization in comparison with centralization.

In light of those approaches, three advantages can be pointed for decentralized systems – e.g., the costs reduction in the transportation of sewage while pumping stations are eliminated, effluent reuse opportunities and, finally, issues found in specific unities do not cause collapse in the whole system (MASSOUD *et al.*, 2009). In relation to some important disavantages, firstly, decentralized solutions tend to be more expensive in terms of implementation and operational and maintenance costs per inhabitant. In addition, there are issues associated with the logistics for dealing with the treatment of subproducts.

Summing up, sets of decentralized systems, or also called distributed systems, for small and big communities represent practical, localized and highly networked approaches. While centralized WWTS, or so-called central infrastructure, adopts arterial roles, and even though it might solve the lack of SS systems as well as decentralization, they often have higher costs and more difficult implementation than localized levels of WWTS solutions.

3.2.3 Main Characteristics of Domestic Sewage

Besides defining the characteristics of the system in relation to the types of reactors and kinetics involved, to aknowledge the natural conditions of the sewer has a fundamental role in designing and operating WWTS. Moreover, in late 20th century, the main analysed criteria to mitigate the effects of the wastewater were Biochemical Oxygen Demand – BOD and Total Suspended Solids – TSS (LESSARD; BECK, 1991).

In spite of the importance of the analysis of these indicators also in present days, the cited authors have also stated additional concerns in regards to receiving water bodies. In this view, new components of diversity have increased and hence become indispensable to measure. MetCalf and Eddy (2014) present details of the main indicators which are widely used to characterize domestic sewage, and their influences in water bodies. As highlighted in Table 3, this research compiles the parameters from different studies, which were divided into three criteria, namely: physical, chemical and biological.

TABLE 3 – MAIN COMPONENTS OF THE WASTEWATER

Criteria	Indicators	Definitions [A]
Physical	Total Solids	It is the main physical characteristic and can be divided in suspended solids, volatile, fixed, settlement, and others. In addition, high rates of suspended solids present in the effluent might induce anaerobic conditions in water bodies.
	Turbidity	To evaluate the cloudiness of the influent and effluent in order to measure quality.
	Color	Equivalently to odor, color is used to determinate qualitatively the “condition” related to the age of the wastewater.
	Odor	It describes the condition and the type of wastewater discharged from toilets or industrial, for example.
	Conductivity	To evaluate if the effluent can be used for irrigation.
Chemical	Nutrients: Nitrogen (N) and Phosphorus (P)	Although nutrients are considered indispensable for growing life in the ecosystems, both Nitrogen and Phosphorus discharged in high amounts in water bodies might cause eutrophication.
	pH / Alkalinity	The condition of the acidity or basicity and the buffer capacity are essential to understand if biological activity can occur in the wastewater, and hence the type of the WWTS.
	BOD / COD	The Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are essential for comprehending the depletion of the Oxygen resources within the water bodies.
Biological	Coliforms	It may be divided into total and thermotolerant, and they are measured to evaluate the presence of pathogenic bacteria.
	Specific Microorganisms	To evaluate the presence of other microorganisms such as protozoa, helminths, virus, among others.

SOURCE**:** Adapted from MetCalf and Eddy (2014); Henze *et al*. (2008)

Even though Table 3 presents a set of important parameters related to water/wastewater quality, that are usually used to measure the performances of WWTS, this study has stablished a particular method to consider a smaller set of those.

3.2.4 Example of Different Effluent Discharge Classifications

The standards of the effluent from WWTS may vary from scenario to scenario, reflecting the specificities and necessities according to the reality of each country and state, for instance, development stage of the scenarios, economic level, commitment to environmental protection, amongst others.

In this view, from Table 4 to 7, different examples of minimum ranges of reduction are exemplified, starting from the European Union directives (Table 4).

TABLE 4 – EFFLUENT DISCHARGES ACCORDING TO THE EUROPEAN COUNCIL

Parameter	Concentration	Minimum percentage of reduction	Notes
BOD_5	25 mg/L O2	70–90 %	–
COD	125 mg/L O2	75 %	–
Total suspended solids	35 mg/L 60 mg/L 150 mg/L	90 % 70% –	P.E. greater than 10,000 inhab. P.E. between 2,000 and 10,000 inhab For pond effluents
Total nitrogen	10 mg/L 15 mg/L	70–80	P.E. greater than 100,000 inhab P.E. between 10,000 and 100,000 inhab.
Total phosphorus	1 mg/L 2 mg/L	80	P.E. greater than 100,000 inhab. P.E. between 10,000 and 100,000 inhab

SOURCE: Council of the European Communities (1991).

Moreover, in Table 5 the guidelines for safe use of wastewater in agriculture specifically in terms of infectious diseases are presented. It intends to demonstrate in different standards the bacterial limits of the effluents from WWTS.

TABLE 5 – GENERAL STANDARDS FOR USING WASTEWATER IN AGRICULTURE

Category	Reuse conditions	Exposed group	Intestinal nematodes (eggs/L) (arithmetic mean)	Faecal coliforms (FC/100 mL) (geometric mean)
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	Workers, consumers, public	≤1	≤1000
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees	Workers	≤1	No standard recommended
C	Localised irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable

SOURCE: WHO (2006).

Given the contextualization of the main components of wastewater, a Brazilian regulation (BRAZIL, 2011), namely CONAMA 430/2011, complements and modifies the previous regulation which standardizes the parameters' limits in classes (Table 6), and hence the quality of a specific water body.

However, it is still quite complex to measure the quality of the effluent discharged into water bodies from a WWTS by using the regulation mentioned. Exemplifying the BOD component, which is one of the very common measurements related to organic matter, the cited Brazilian regulation requires a maximum value of 3 mg/L for Class I. In the cases of Classes II and III, the amount of BOD is between 5 and 10 mg/L, respectively.

Additionally, there are other innumerable indicators which are not often, or essentially, measured in relation to sewage concerns, for instance, some elements such as heavy metals like dissolved aluminum (in which the maximum limit amount for this indicator is 0.1mg/L for Class I), and inorganics parameters.

Furthermore, the analysis also depends on several factors regarding water bodies – e.g., original flow regimes and biota characteristics. Despite those two aspects, the decision-makers have been using a classification similar to CONAMA 430/2011 within their decision analysis process.

TABLE 6 – ADAPTED CLASSES OF RIVERS THAT RECEIVE EFFLUENT DISCHARGES IN BRAZIL

Classes of the river	Expected Characteristics				
	Human Consumption	Ecosystem	Recreation	Use	Irrigation
Especial Class	Consumption permitted after disinfection	Aquatic Protection	Primary contact: swimming, diving and water skiing (high risks of ingestion)	Aquaculture and fishing	Vegetables and fruits
Class 1	Consumption permitted after Simplified Water Treatment (WT)	Aquatic Protection and Improvements of Water Quality (WQ)	Primary contact: swimming, diving and water skiing (high risks of ingestion)	Aquaculture and fishing	Vegetables and fruits
Class 2	Consumption permitted after Conventional WT	Aquatic Protection and Improvements of WQ	Primary contact: swimming, diving and water skiing (Medium risks of ingestion)	Aquaculture and fishing	Vegetables and fruits
Class 3	Consumption permitted after Conventional or Advanced WT	Aquatic Protection and Improvements of WQ	Secondary contact: navigation and fishing (Sporadic ingestion)	Recreational fishing, animal drinking	Tree crops
Class 4	Consumption permitted after Advanced WT	Scenario Remains Equal	No recreational activities permitted	No use	No Irrigation

SOURCE: CONAMA Regulation 357/2005 - Brazil (2005)

Even though the responsibilities for collecting and treating wastewater belongs to the municipality jurisdiction, it is relevant that the regulation does not consider rivers (BRAZIL, 2007). Regarding this context and regulation presented in Table 6, a supposed community could provide the necessary infrastructure to obey the quality of the discharged effluent into a hypothetic river. However, another upstream city that encompasses the same river could not implement adequate sanitary mitigation. In this whole scenario, obviously the problem of contamination would not be integrally solved.

Nevertheless, this research dicusses the possibility to provide an evaluation procces which intends to facilitate the decision making for all scenarios involved, respecting the necessities of each local situation. Hence, considering the cited upstream and downstream scenario, the following instrument intends to support decisions in both cases separately or collectively.

Finally, likewise the parameters and criteria used in CONAMA 430/2011, a classification will be employed in the second step of the adapted DMA process defined for this research. Additionally, the details regarding the requirements to attend those classes are also depicted in the material and methods chapter.

3.2.5 Basic Principles of the Wastewater Treatment Systems Processes

Basically, within the WWTS process there are specific levels in which each one has individual aims. The objective of the preliminary is to remove suspended coarse solids in order to enhance the upcoming stages of the treatment process. The preliminary stage can be aggregated with the next step, which is named primary treatment.

In the primary devices, the treatment process is generally equipped with mechanically driven scrapers, and afterwards designed with sedimentation tanks, not only to settle suspended solids, but also a small fraction of the organic matter (WBG, 2016). The average efficiency for the removal of total suspended solids (TSS) within the primary stage is 50 to 60%, while in terms of BOD it is between 20 to 30% (WBG, 2016).

The biological or secondary treatment aims to dissolve almost the totality of the remained portion of the organic matter. This assignment is accomplished by the activity of bacterial presence in the water. This last device is generally followed by a settling tank (WBG, 2016). Hamza *et al*. (2016) emphasize that biological treatment seems to be more attractive given its economic advantages over other treatment processes. It also permits to convert waste into renewable energy, for instance biogases and biosolids, while in addition degrades industrial sewage compounds without producing toxic by-products (HAMZA *et al*., 2016).

The technologies at this stage generally include Activated Sludge Process (ASP), Waste Stabilization Ponds (WSP), Constructed Wetlands (CW), amongst others. Although operational conditions of secondary systems can be modified to remove some group of nutrients, only those correlated with the increasing of micro-organisms participating in the process of breaking down the organic matter are eliminated (SALA-GARRIDO *et al*., 2011).

Finally, according to (WBG, 2016), the tertiary treatment (also called polishing or advanced) has the characteristic of removing pathogens, heavy metals, and other elements that escape from the previous steps. In many cases, this stage of treatment and removals are simply achieved by modifying conventional secondary WWTS. For instance, processes that enclose flocculation, precipitation and chemical oxidation, chlorination and pH correction are considered tertiary WWTS (WBG, 2016). Conclusively, MetCalf and Eddy (2014) add that disinfection typically occurs in this stage of treatment.

In addition, when the goal is to reclaim the wastewater, it can also be highlighted the elevated efficiency in the disinfection level, which is typically made with chemicals (chlorine) or ultraviolet radiation process (WBG, 2016). However, due to the important concerns about the chlorine residuals in the effluent as well as the high costs involved considering those technologies, chlorinification is not often designed for the treatment of domestic sewage.

As seen in Table 7, von Sperling and Chernicharo (2005) have already summarized the specified treatment levels in terms of removal characteristics.

TABLE 7 – WASTEWATER TREATMENT LEVELS

Level	Removal
Preliminary	• Coarse suspended solids (larger materials and sand)
Primary	• Settleable suspended solids • Particulate (suspended) BOD (associated to the organic matter component of the settleable suspended solids)
Secondary	• Particulate (suspended) BOD (associated to the particulate organic matter present in the raw sewage, or to the non settleable particulate organic matter, not removed in the possibly existing primary treatment) • Soluble BOD (associated to the organic matter in the form of dissolved solids)
Tertiary	• Nutrients • Pathogenic organisms • Non-biodegradable compounds • Metals • Inorganic dissolved solids • Remaining suspended solids

SOURCE: von Sperling and Chernicharo (2005)

In the same vein, von Sperling and Chernicharo (2005) have adequately summed up and depicted that the main objective of the preliminary is to remove coarse solids. The primary level, on the other hand, aims to start the removal process of settleable solids and part of the organic matter wherein only physical pollutant removal mechanisms occur. In the secondary level, the goal is to remove organic matter, and perhaps nutrients (nitrogen and phosphorus), by performing biological mechanisms. Finally, the tertiary specifically aims to eliminate particular pollutants, usually toxic or non-biodegradable compounds, for instance. Another description to define the tertiary level is the complementary capacity to remove pollutants that were not removed in the secondary stage.

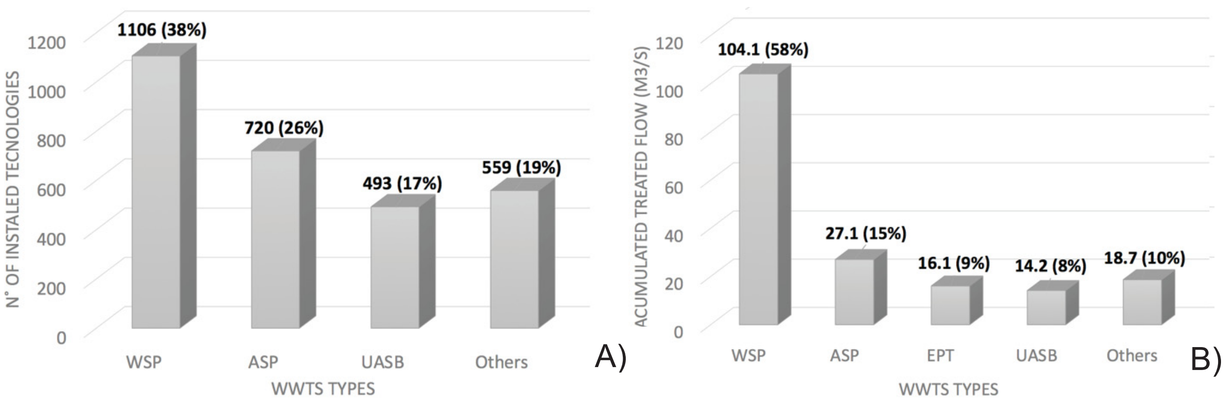
Finally, the adequate integration of each stage (e.g. preliminaries, primaries, secondaries, tertiaries, etc.) within the whole process implies the effectiveness of the treatment. The following subsections briefly discuss the distribution of the types of processes in similar scenarios of this applied study, and also the thematic related to sustainable WWTS.

3.2.6 Distribution of Types of System in the Developing World

According to a study by Noyola *et al.* (2012), after the examination of 2,734 WWTS in six Latin American and Caribbean (LAC) countries in terms of representativeness, it was noticed that the three most used technologies are Waste Stabilization Pond (WSP), activated sludge process (ASP) and Upflow Anaerobic Sludge Blanket (UASB) reactor.

As it can be seen in Figure 5-A, those systems represent nearly 80% of the total number of WWTS with regards to the sample analysis in LAC countries. Similar results are shown in Figure 5-B where it is demonstrated the systems in relation to the treated wastewater flow.

FIGURE 5 – DISTRIBUTION OF DIFFERENT TREATMENT TECHNOLOGIES IN LATIN AMERICAN COUNTRIES: (A) BY NUMBER OF SYSTEMS; (B) BY ACCUMULATED FLOW

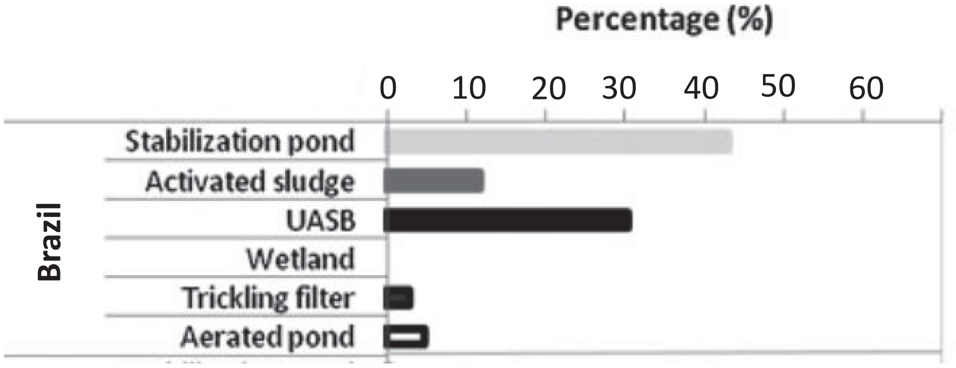


LEGEND:
WSP – Waste Stabilization Pond
ASP – Activated Sludge Process
UASB – Upflow Anaerobic Sludge Blanket
EPT – Enhanced Primary Treatment

SOURCE: Adapted from Noyola *et al.* (2012).

As seen in Figure 5-B, the type of system “Enhanced Primary Treatment” can be more representative in comparison to UASB in LAC countries. Nevertheless, in terms of percentage distribution in Brazil, approximately 85% of the total flow is treated by ASP, UASB and ASP (NOYOLA *et al.*, 2012), as shown in Figure 6.

FIGURE 6 – DISTRIBUTION OF DIFFERENT TREATMENT TECHNOLOGIES IN BRAZIL



SOURCE: Adapted from Noyola *et al.* (2012)

Finally, and supporting this trend, in a research by Kalbar *et al.* (2012) it is also advocated that the most widely used type of WWTS is the ASP, followed by others, WSP and UASB, for instance.

3.2.7 Sustainable Wastewater Treatment Systems

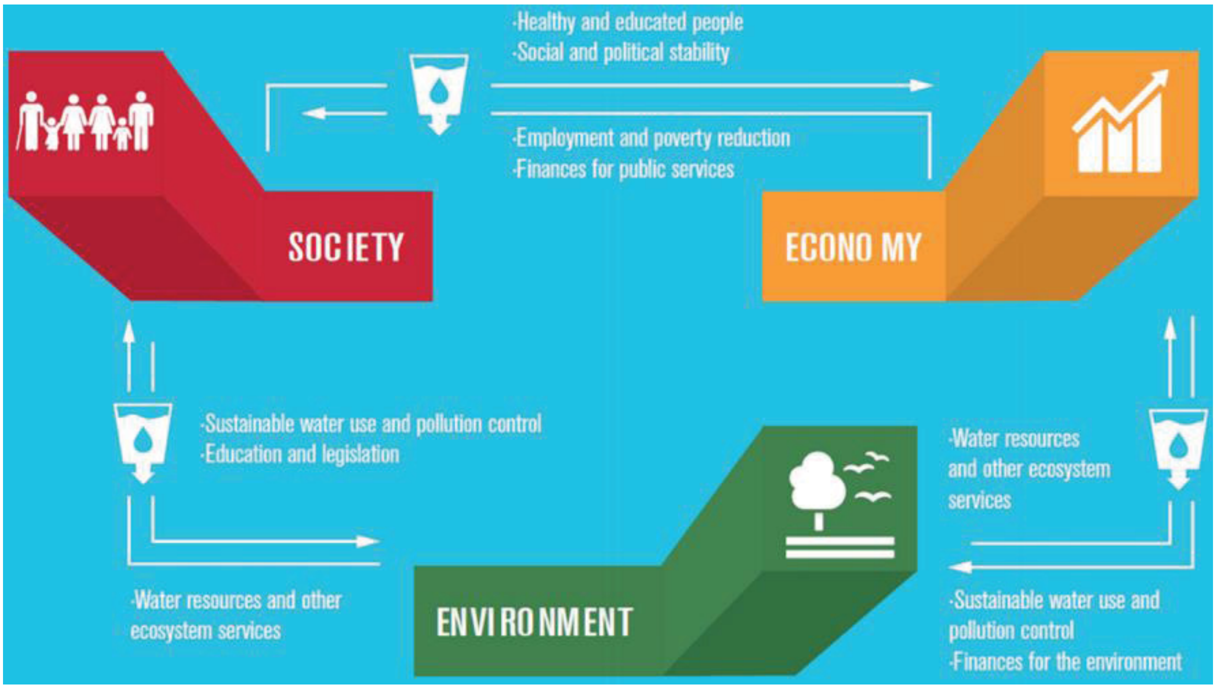
3.2.7.1 Introductory concepts

One of the most common meanings of sustainability is the probability of the system being beneficial over its required period of use (UJANG; HENZE, 2006). Indeed, the academic literature often refers to the term sustainability as the property of the WWTS to consider natural aspects, hence not using nearby resources and bio-products generation. Wilderer and Grambow (2016, pg. 147) state that “sustainability stands for human activities kept in the limits of the generic capacity of the Earth’s life supporting system”.

In light of this approach, terms such as sustainability and naturality may be strictly close due to the fact that technologies related to sustainable WWTS can be defined as those which use natural materials and processes (e.g. plants and microorganisms), and also allow to recover by-products generated within the system (e.g. biogas and fertilizer).

On the other hand, the 2030 Agenda (UN-WATER, 2016) relates sustainability with the balance of three dimensions to achieve appropriate water management and water-hazard resilient infrastructures. Figure 7 summarizes this alternative approach.

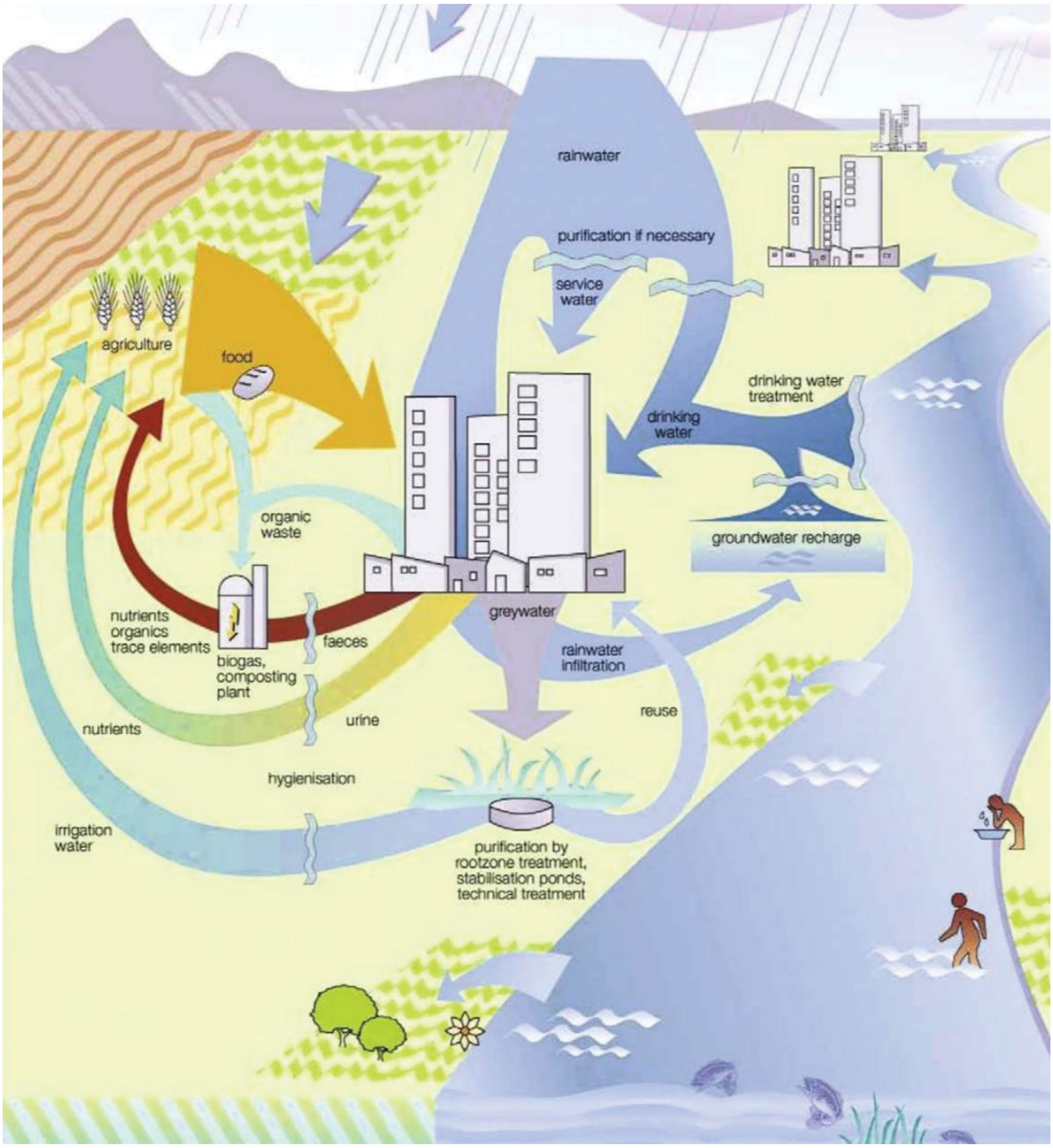
FIGURE 7 – THE THREE MAIN APPROACHES OF SUSTAINABILITY IN WATER MANAGEMENT



SOURCE: UN-WATER (2016).

In this view, there is another denomination that has also been correlated with sustainability, which have been used by researchers recently. The ECOSAN (Ecological Sanitation) was created by a group of researchers focused on developing systems that could both treat the wastewater and reuse nutrients and energy within the process. Werner *et al.* (2009) and Zhou *et al.* (2010) corroborate with those aims and also define ECOSAN as a set of measurements and technologies capable to solve environmental issues by using principles which consider ecological integrity, and proper management of waste treatment and maintenance systems. Figure 8 summarizes the principles of the ECOSAN by showing the cycle of water, as well as wastewater and sub products generated within the process. It can also be seen that the cycle of nutrients is a closed loop, which circulate between the urbanized areas and agriculture sites.

FIGURE 8 – ECOSAN'S ADVANTAGES SCOPE



SOURCE: Adapted from Werner *et al*. (2009)

According to Werner et al. (2009) some of the main advantages of ECOSAN are: (i) Improving the health of the water bodies and the population by minimizing the release of pathogens from wastewater into the water cycle; (ii) Promoting recycling of the components of the process (e.g. nutrients, organic, water and energy); (iii) Conservation of natural resources by reducing the consumption; (iv) Preference for modular and decentralized systems favoring the reduction of costs; and other benefits.

Finally, recent studies that involve the application of principles and techniques of the ECOSAN have been appearing in the literature and also providing innovative views in the field of WWTS, notably in the developing world, as seen in the following three topics.

3.2.7.2 WWTS alternatives that approach sustainable principles

Ayaz and Akça (2001) corroborate the introductory concepts regarding sustainability and ECOSAN in the field of WWTS. The authors have advocated that constructed wetlands (CW) are appropriate examples of sustainable systems given its properties of being affordable and easy to operate. Moreover, according to Vymazal (2013), wetlands are hybrid systems where treatment is generally conducted in stages, with wastewater flowing vertically, then horizontally. The author has made a comparative analysis of sixty different types of CW built in twenty-four countries. In the same study, the systems have aimed to treat wastewater from both household and industrial sources.

Given this approach, one might say that the solution for the problem in needed regions could be CW as a secondary WWTS system. Nevertheless, there is an important disadvantage related to this system in peri-urban areas. As wisely argued by Ayaz and Akça (2001), CW requires large areas to implement the systems. Notwithstanding these limitations, within the scenario of peri-urban areas in which there are not ample available areas, land needs seems to be an essential factor to consider when making a decision related to choosing a suitable WWTS.

That is one of the reasons why this study proposes a not so familiar WWTS for developing countries. The Ecologically Engineered Treatment System (EETS) was also considered a sustainable solution alternative and was presented given its design characteristics as it can be seen further.

3.2.7.3 Presenting the EETS as an Alternative

As reported by Roggenbauer (2001), the ecological engineering WWTS, or the so-called Ecologically Engineered Treatment System (EETS), was created in the late eighties and early nineties in North American countries. The author documents that the first EETS facility was opened in the city Providence, Rhode Island in 1989.

Afterwards, another EETS was built in 1990, in Harwich, state of Massachusetts (USA), as mentioned by Teal and Peterson (1993) and also corroborated by Roggenbauer (2001).

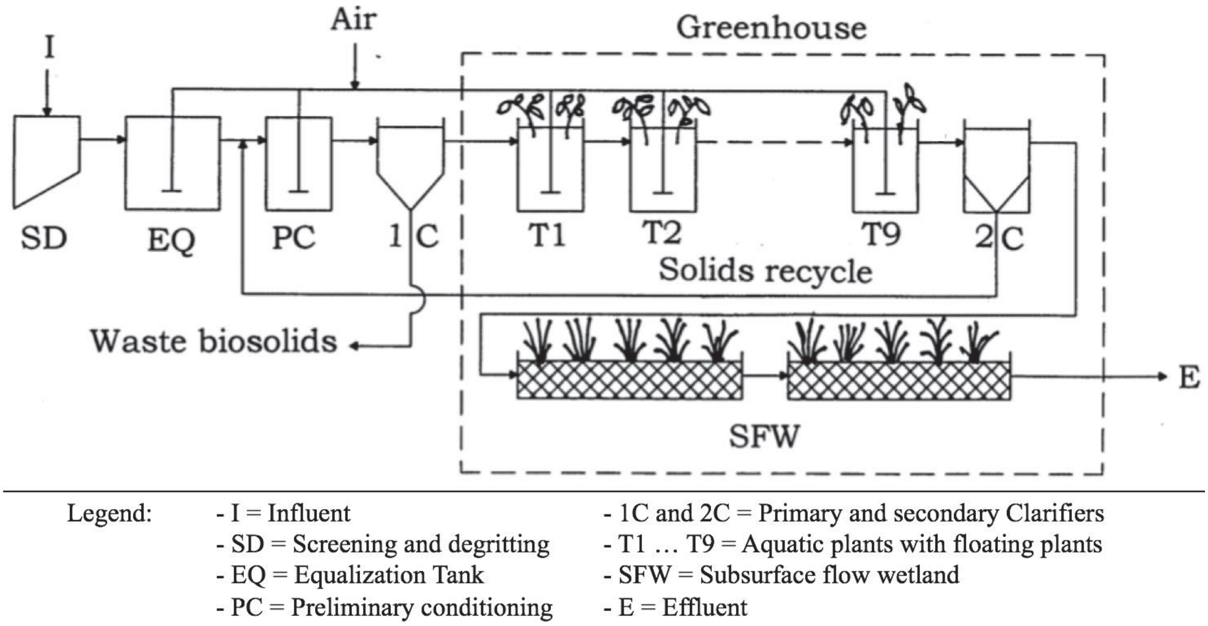
Additionally, Steinfeld and Porto (2004) have reported that another EETS facility can be found in Weston, also in Massachusetts. Hamersley *et al*. (2001) argued that the EETS was previously designed to treat by-product generated on the wastewater treatment, exclusively from households. However, the EETS was further developed also for treating raw sewage.

In this view, previous research has stablished that the EETS basically works as a treatment process composed of tanks connected in series which have diversified ecological functions (MOHAN *et al*., 2010; KUMAR *et al*., 2011). One of the particularities of the EETS's design comprehends sequential integration of different ecological microenvironments granted by floating macrophytes (Eichhornia crassipes), submerged–emergent macrophytes (Oriza sativa) and submerged-rooted microphytes (Limna gibba), all of them cultivated in joint or separate tanks (KUMAR *et al*., 2011). In all those three environmental plants scenarios occur mainly organic matter reduction and nitrification through biological processes. Teal and Peterson (1993) also explain that the train of reactors of the EETS design has the property of treating the wastewater biologically through a sequence that commences by blending, aeration and settlement tanks, before it goes to a sand filter and constructed wetland.

Given the natural environment concerning the aquaculture within the system and also considering the climate where EETS were previously implemented, Teal and Peterson (1993) firstly observed that the set of devices which incorporate floating plants should be implemented inside a greenhouse. The intention was to maintain a propitious condition for the plant's survival by adequate operating temperatures.

Summing up, Todd et al. (2003) states the whole process of the EETS as a system that includes aeration and activated solids recycling. The authors add that the devices combine aquatic environments and wetland components, without the addition of any type of chemicals. Figure 9 briefly presents the design of the EETS's framework.

FIGURE 9 – ECOLOGICALLY ENGINEERED TREATMENT SYSTEM’S (EETS) DESIGN



Source: Hamersley et al. (2001)

As seen in Figure 9, the EETS is considered secondary treatment since it is achieved only by biological processes, or devices (e.g. aeration tanks), wherein enhanced organic matter removal occurs.

Furthermore, even though the EETS process is based on ASP treatment mechanisms, an additional effluent polishing (e.g. supplementary organic matter removal, and eventually increased nutrients removal) might be achieved within specific devices, for instance, in the aeration tanks by the roots suction of surface plants, also in the sand filter, and finally in the CW.

It is also noticeable that even though the treatment is similar to the ASP, two important differences can be highlighted: (i) first, regarding the aeration tank, where in the case of the EETS it includes components such as plants, algae, snails, and zooplankton, all working in the treatment process; (ii) secondly, with respect to the group of people to be served, the EETS intrinsic design is highly adequate for intermediate communities under 5 thousand people, for instance.

Regarding the floating plants, one of the adversities is the necessity of harvesting and thereafter the disposing of those elements. However, adequately managed, those organic subproducts can be converted into fertilizer. Moreover, the system was created for decentralized approaches.

Additionally, Mara (2003) argued that one of the obstacles for implementing ASP is related to high construction costs, especially in the developing world and therefore in poor communities. He also adds that there is a necessity for developing and seeking affordable alternatives, such as the EETS.

Moreover, according to WEF (2010), the floating plants within the aeration tank, and occasionally in the gravity clarifiers, create an effective aquaculture environment component for treating wastewater. It is achieved through the uptake of wastewater constituents, and most importantly through the attachment of substrate in their roots. This whole process is responsible for a significant portion of the treatment provided in terms of organic matter and heavy metals adsorption by the roots.

In addition, the EETS do not require the use of chemicals or polymers, and the cycle of nitrogen occurs within the process due to the aerobic (aeration tanks) and anaerobic (CW) conditions. Hamersley *et al*. (2001) added the information with reference to the biological nitrification (ammonium converted into nitrite and nitrate) and denitrification process that can be observed in the treatment process.

As previously mentioned, the greenhouse was designed to control the internal temperature and provide the necessary conditions for the treatment process. It is thoroughly understandable due to the fact that the majority of the systems was constructed in temperate zones, where the average temperatures in the winter time often reach negative measures. Still, in tropic/subtropics countries such as Brazil, where the temperature often varies from 15 to 30 ^{o}C in averages throughout the year in almost the whole country, the original configuration considering the greenhouse can be adapted or perhaps removed from the EETS. It might result in cost and maintenance reducing, construction celerity, and hence the system can be more attractive to be implemented in peri-urban areas.

Finally, according to the Ecological Engineering Group (2016), the EETS integrates on its processes benefits in both social and environmental aspects, since it prevents infectious diseases by treating wastewater, and by generating useful by-products (e.g. reclaimed water).

3.2.7.4 Recovering useful by-products by the EETS

Regarding the EETS`s characteristics and also the ECOSAN's concepts, it is possible to correlate sustainable practices within this type of WWTS. In some way, both consider the importance of acknowleding the loop of the input components, in particular organic matter and nutrients loads, for instance. Even though the wastewater components may enter as a mixed flow, they are converted within the treatment into several different products before being discharged in watercourses and ecosystems.

In this view, although wastewater has been considered for a long period a potential health hazard in urban agglomerations, understanding that components of sewage can be converted into fertilizer, for example, is a developing concept (HENZE *et al*., 2008). Still, the use of treated sewage may continue to be a health problem if without adequate control. In other words, proper handling and manegement of the sewage could contribute to supply several needed basic inputs for communities' activities in different scenarios.

In fact, even though the amount of sewage produced by a small municipality may not be highly significant for irrigation, the procedure of using solid outputs (sludge) from WWTS in irrigation and agricultural sites has been widely adopted in developing countries, such as Brazil. In other words, the contribution of nutrients, whose demands are variable according to the characteristics of the soils and the crops, definitely complements and provides mineral fertilization of the harvest site. Factors such as the final use of the soil, growing cultures and characteristics of the substrate are always necessary to be acknowledged in order to effectively control the nutrients doses. In the same vein, the importance of organic matter in irrigation is unquestionable for the soil fertility. Indeed, it basically contributes to the soil microbiological activity and also provides its granular structure, porosity, and moisture retention.

Summing up, one of the important goals of the EETS is to create ecosystem-based technology to treat wastewater by protecting and regenerating human and natural communities with biodiversity. However, it is possible to consider the concepts of the looping of sewage components within the ETTS in terms of hydroponics. In fact, given the devices which constitute the WWTS, namely aeration tank and constructed wetland, there are plants that evidently absorb, during their life cycle, those cited components that are flowing with the sewage within the system. As stated in PROSAB (2009), the roots are fed by direct contact with the solution or using an inert substrate carrier. Still, these types wherein plants are integrated within the treatment, harvesting and disposing require additional operational and maintenance assistance provided by supplementary employers.

3.3 DECISION MAKING ANALYSIS (DMA)

According to Marttunen *et al*. (2015), the main approach of DMA is that the process should be flexible considering the fact that it involves many groups of different criteria, for instance indicators, alternatives and participants. Since the late 19th century, many researches have been creating different and complex methods in order to evaluate the most suitable solutions related to Water Treatment Systems (SCOTT *et al.*, 2012), and more specifically regarding WWTS (MUGA; MIHELCIC; 2008), to a given scenario.

In this view, there is a constant need in the academic literature for the decision making processes in the field of WWTS to be simple and easily understood by the users, amongst other characteristics. For example, Loetscher and Keller (2002) state that even if not necessarily producing definitive solutions, at least providing the users information to avoid taking decisions seriously wrong.

In this view, the term water governance related to decision making comes in the same direction. Yet relatively new, according to the OECD (2015a), it is related to the set of rules, practices, and general processes that aims at taking decisions for the management of water resources and services to be further implemented.

Lienert *et al.* (2016) have studied multiple elicitation methods to support the decision of WWTS, and hence have stated that decisions in the field of environmental approaches comprehend important impacts in a society, for instance. Given that governmental resources usually finance the products of decisions, it should be suitable in the long term.

Therefore, there are other several different DMA processes to support collaborative and participatory generic decisions, for instance, it can be cited the Multi Criteria Decision Analysis (MCDA), Multiple Attribute Decision Making (MADM), Multi Criteria Decision Making (MCDM), Multiattribute Utility Technique (MAUT), Analytic Hierarchy Process (AHP), Benchmarking process, Life Cicle Analysis (LCA), Structured Decision Making (SDM), among others.

According to Gregory *et al*. (2012), there is a tendency of some of the cited DMA processes (e.g. MCDM and AHP) to underestimate important steps of the whole DMA method. In other words, in the cases of both processes, they might not consider sufficient attention about the first DMA steps, for instance detailing scenarios, issues and participants, or also within the identification of objectives and performance measures. Thus, it can also lead the decision makers to biased or misleading results. Additionally, the same cited authors have stated that the AHP and MCDM approaches also tend to be more linear and it results in less attention to the iteration and monitoring steps.

Moreover, Loestsche and Keller (2002) have also reinforced that there are some lacks in terms of monitoring steps in respect to the AHP and MCDA. Additionally, the authors state that, although highly usable in comparison analysis, the AHP can be described as inappropriate given the several numbers of paired correlations required in the field of selecting WWTS alternatives. In this view, one of the important concerns of using those cited decision making methods is that they might produce unreliable and confused outcomes.

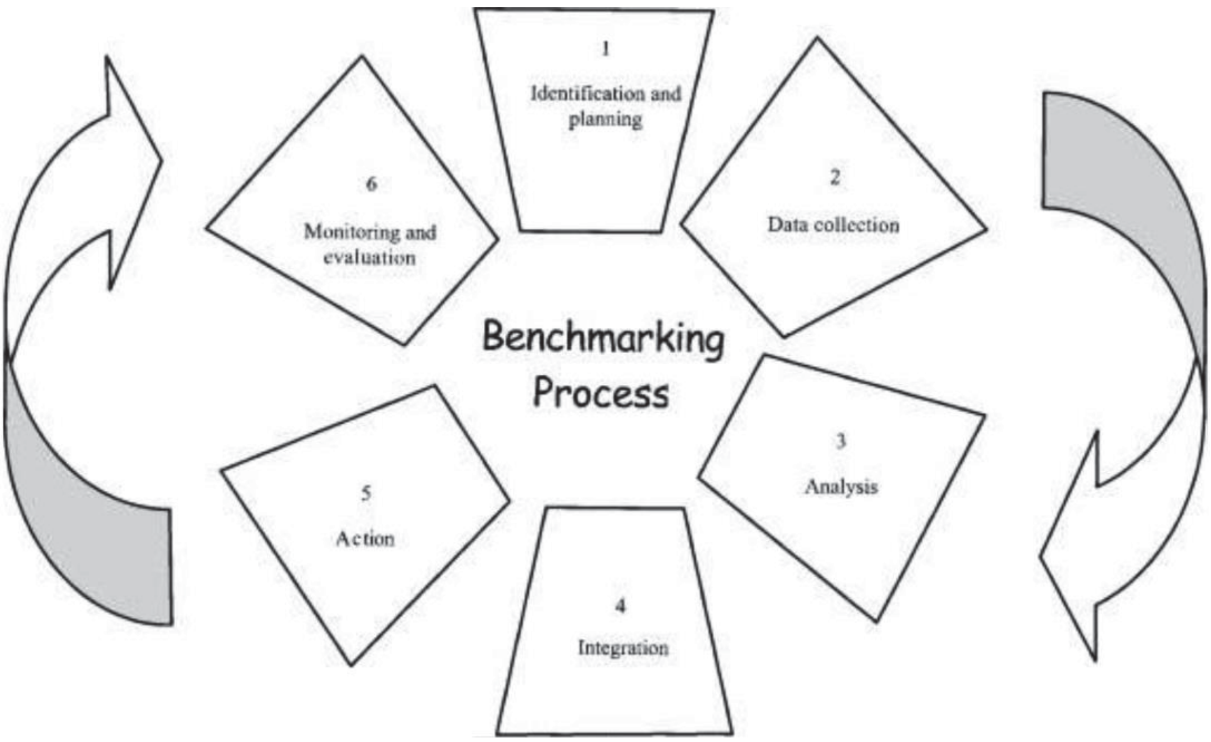
In the view of other supporting DMA that have been applied in the SS field, the Life Cycle Assessment (LCA) can also be highlighted. Yoshida et al. (2014) define a relevant direction to the LCA issue. The authors have shown the LCA objectives to enable quantitative and qualitative evaluations and trade-offs by assessing diverse indicators, especially regarding the environmental aspect. Corominas et al. (2013) and Zang et al. (2015) corroborate the statement of LCA focusing on environmental concerns rather than others. They have defended that the LCA has been proved as a legitim instrument to evaluate environmental effects (e.g. eutrophication potential, global warming potential, toxicity-related impacts, energy balance, water use, land use, etc.) related to the WWTS decisions making and implementation.

In addition, LCA has been applied in a recent research (AMARAL, 2018) of the same post-graduate program as the author of this research. She has aimed to evaluated sustainability concerning four different scenarios of treatment and final destination of biological sludge and biogas, by using the computer ReCiPe 2016 tool. Her results have shown that by applying the LCA, the three main dimensions of the sustainability could be evaluated. Nevertheless, the cited author has mostly focused on the analysis of each dimension separately, rather than integrated. This research intends to fulfill an important and diversified point of view by proposing the use of an adapted SDM.

The PROSAB (2009) has also presented the decision making approach in its report. Nevertheless, the focus was not to introduce a strucutured mechanism, but rather to discuss the main objectives of taking a decision regarding WWTS. In this view, the cited report mainly approaches the concept of the route of the final effluent, for instance, paying attention to the quality of the receptor water body or if it can be used in agriculture.

Moreover, Malano *et al*. (2004) have highlighted another instrument in their study, the benchmarking process. They have focused on its performance in the irrigation and drainage sector to define the most suitable alternatives. According to the authors, benchmarking implies comparison, and hence provides valuable awareness on the selection of the alternatives. The stages of the benchmarking are illustrated in Figure 10, and as it is seen in the next subtopic, the process may be one of the precursor designs of the method applied in this research (i.e., SDM), given its similar layout, steps and objectives.

FIGURE 10 – BENCHMARKING STAGES



SOURCE: Malano *et al.* (2004).

Table 8 summarizes the most exemplified decision making instruments as cited in this section. Firstly, it depicts if they were adequately experienced in terms of complex decisions. Secondly, it characterizes whether or not the processes have acknowledged a clear feature to integrate them. Thirdly, if they have considered cyclical aspects within their evaluation processes.

TABLE 8 – SUMMARY OF RELEVANT DMA USED IN ENVIRONMENT EVALUATION PROCESS

Instrument	Feasible to complex decisions	Has considered specific attention in the first steps of DMA	Has considered cyclical aspects for improving the evaluate process	References
MCDA	✓	-	-	Aulinas et al. (2011); Kalbar et al. (2012); Scott et al. (2012) and Marttunen et al. (2015)
AHP	✓	-	-	Loetscher and Keller (2002)
LCA	✓	✓	-	Corominas et al. (2013); Yoshida et al. (2014); Zang et al. (2015) and Amaral (2018)
Benchmarking	✓	✓	✓	Malano et al. (2004)
SDM	✓	✓	✓	Gregory et al. (2012) and Robinson et al. (2017)

Notes: MCDA – Multi Criteria Decision Analysis
AHP – Analytic Hyerarchy Process
LCA – Life Cycle Assessment
SDM – Structured Decision Making
Sources: Cited within the table.

In spite of the fact that all of the mentioned processes can be used in complex decisions and hence in the field of SS, much of the current literature pays particular attention to a specific DMA, the SDM. This one has permitted the analysis of complicated subjects, in a way that they pay more attention to the first steps of the decisions and, in particular, considering circular patterns in their structure. It allows feeding the analysis with feedback and new information to be further improved within the DMA process.

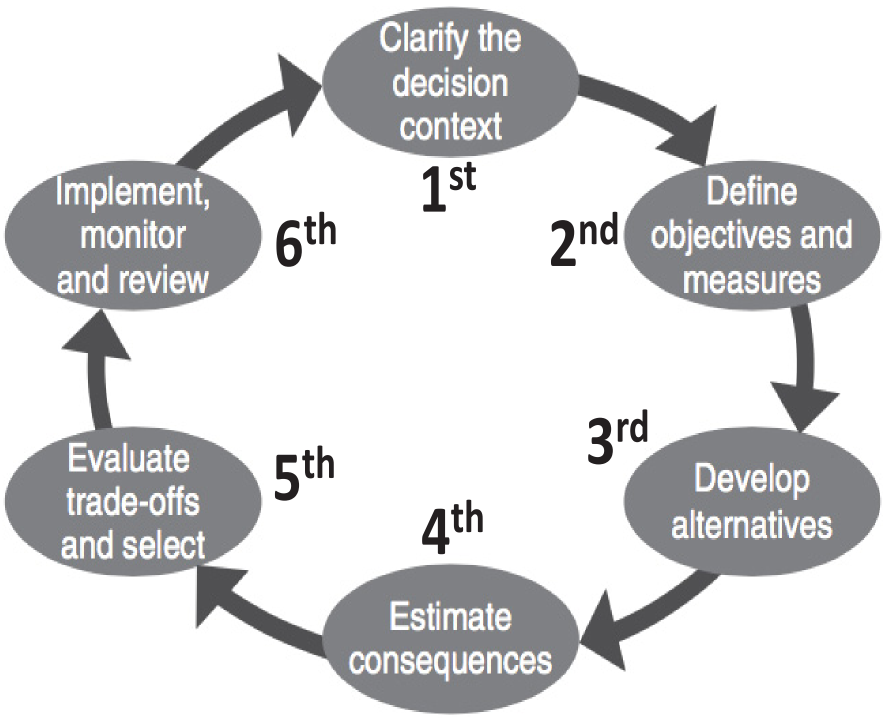
In this view, researches have pointed out that the SDM has been recently reported in a way that it acknowledges adequate techniques in quite complex circumstances (ROBINSON et al., 2017), such as environmental engineering problems (AULINAS *et al*., 2011; KALBAR *et al*., 2012; SCOTT, *et al.*, 2012; GREGORY *et al*., 2012; MARTTUNEN *et al*., 2015). The next subsection elucidates the referred one selected in this research.

3.3.1 Structured Decision Making (SDM) Details

Even though DMA processes have recently been well developed and applied in the field of choosing wastewater treatment alternatives, there is not a unique and ideal WWTS applicable to all cases. That is the reason for requiring individual evaluation for each scenario concerning its specific characteristics. A discrete evaluation can be perceived in the structure and definitions of a widely well-evaluated process, such as the SDM.

An important difference between the SDM and the others according to Gregory *et al*. (2012) is the emphasis on the extensive participation of users in the evaluation and also in allowing participants to think critically about the final decision. The authors summarize the SDM structure as shown in Figure 11.

FIGURE 11 – STRUCTURED DECISION MAKING PROCESS



SOURCE: Adapted from Gregory *et al.* (2012).

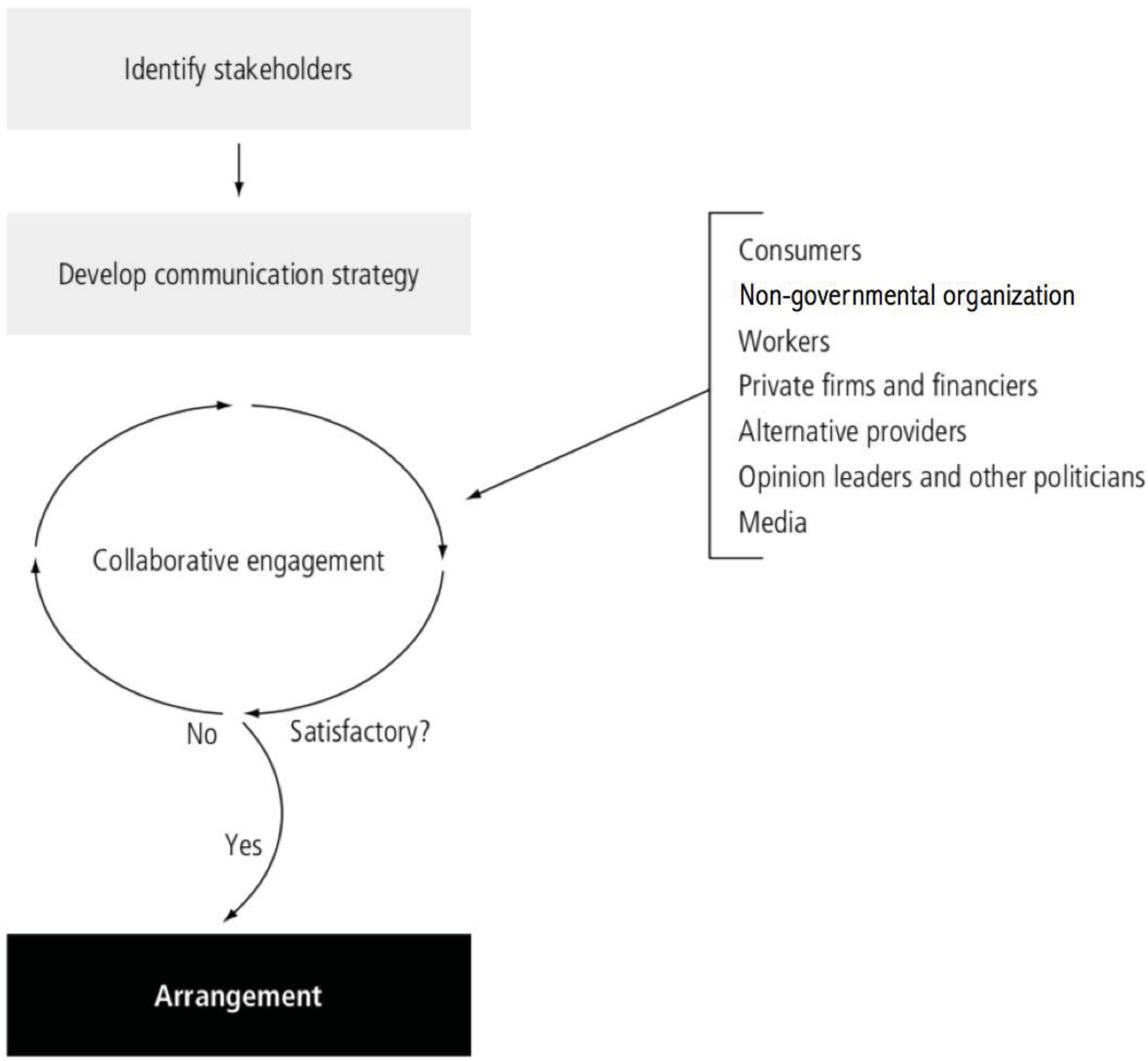
The six steps defined and shown in Figure 11 (GREGORY *et al.*, 2012) can be detailed as follows:

1st - Clarifying the decision context

As stated by Aulinas *et al*. (2011), a supposed DMA process starts specifying the problematic scenario. This is obtained by collecting information of the intrinsic characteristics and issue, for instance, size and types of urban settlement as well as the problematic situation such as community lacking basic needs. In summary, the first step is to define the problem and identify the participants involved.

Concerning the participants, Figure 12 provides an overview of the strategies for involving participants in the decision making analysis process.

FIGURE 12 – STRATEGIES TO INVOLVE PARTICIPANTS IN A PROJECT



Source: WB (2006).

As shown in Figure 12, this step considers identifying those groups that somehow provide relevant information to the process. As stated by WB (2006), “any group that asserts an interest can be treated as a stakeholder” of the decision content. In the water services context, they can be consumers, community-based organizations, workers, private firms, politicians, specialists, amongst others. In this view, the existing literature on defining stakeholders is extensive and focuses particularly on stating that the most important group of participants are usually customers (WB, 2006; MUGA; MIHELCIC, 2008; GUEST *et al*. 2009; OECD, 2015a).

Additionally, there is a relevant factor related to the stakeholder approach, and it is related to the level of government’s responsibility in water governance. In this view, municipality, state, and central government’s levels should have responsibilities for water services, and rather, participation in the decision making process of water governance.

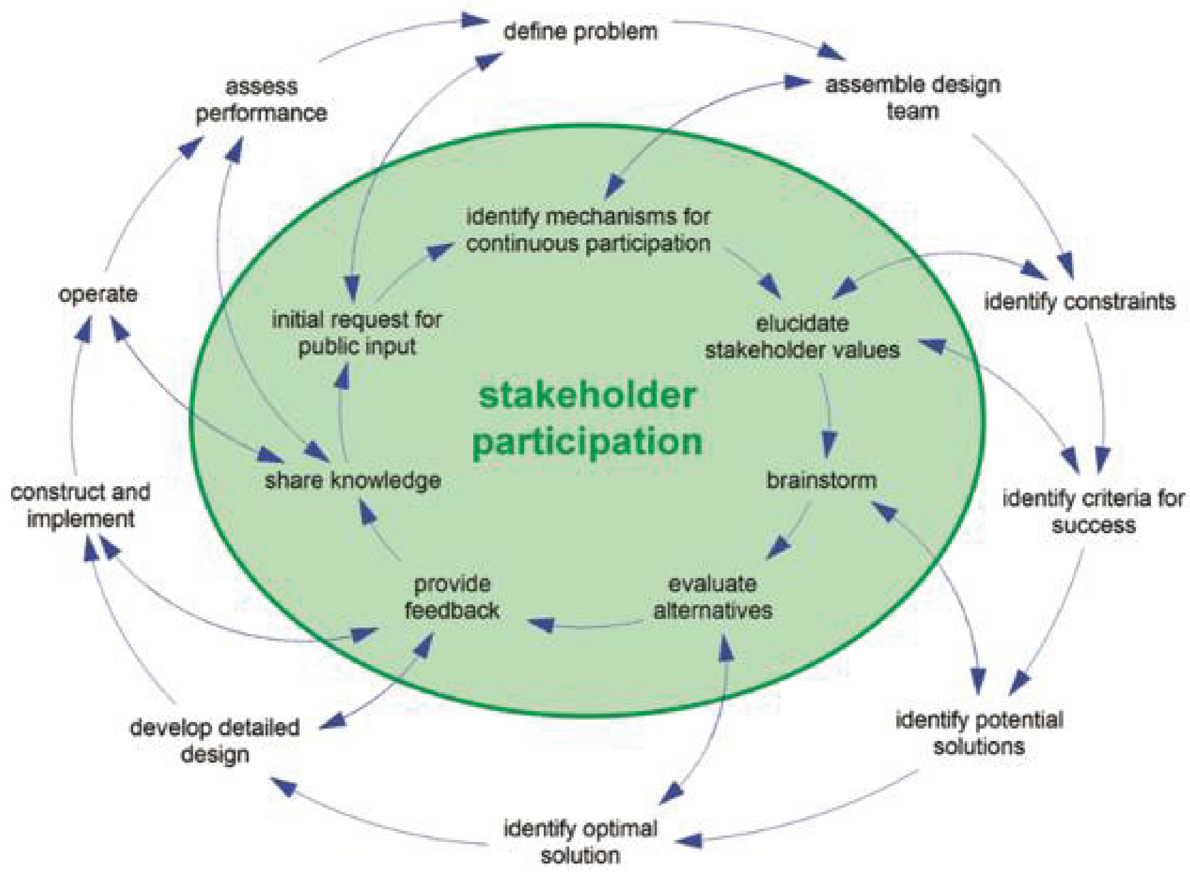
The same point of view is approached by WB (1993), which states that identifying the level of government is the first step when introducing private participation, hence leading the quality of the obtained results. Additionally, the cited report also indicates the importance of identifying key participants and that their interests in the decision making design might also involve outreach to traditionally marginalized groups, for example poor households and people in informal settlements.

Moreover, the success of the whole decision analysis depends on another important factor. The interaction of the selected groups is certainly relevant in order to obtain the set of preferences and perspectives of each group (WB, 2006). The way to involve participants, demands expertise of the manager, and these participants rely upon the purposes and objectives of the DMA. The cited report also suggests few types of interaction, for example, collection of information, consulting, deciding together, amongst others. Whereas the ways of communication are dependent on the type of interaction, which can be through the application of polls and surveys, focus groups, or also open forums.

In this view, it is necessary to contemplate adequate participatory plannings in order to acknowledge this component within the process. Additionally, through the incorporation of stakeholders in the analysis, project managers can “facilitate positive social learning, minimize and resolve conflicts, elicit and use local knowledge, and achieve greater public and stake holder acceptance of water management decisions”

(GUEST *et al*., 2009, pg. 6129). The contributions of the stakeholders can be achieved as depicted in Figure 13.

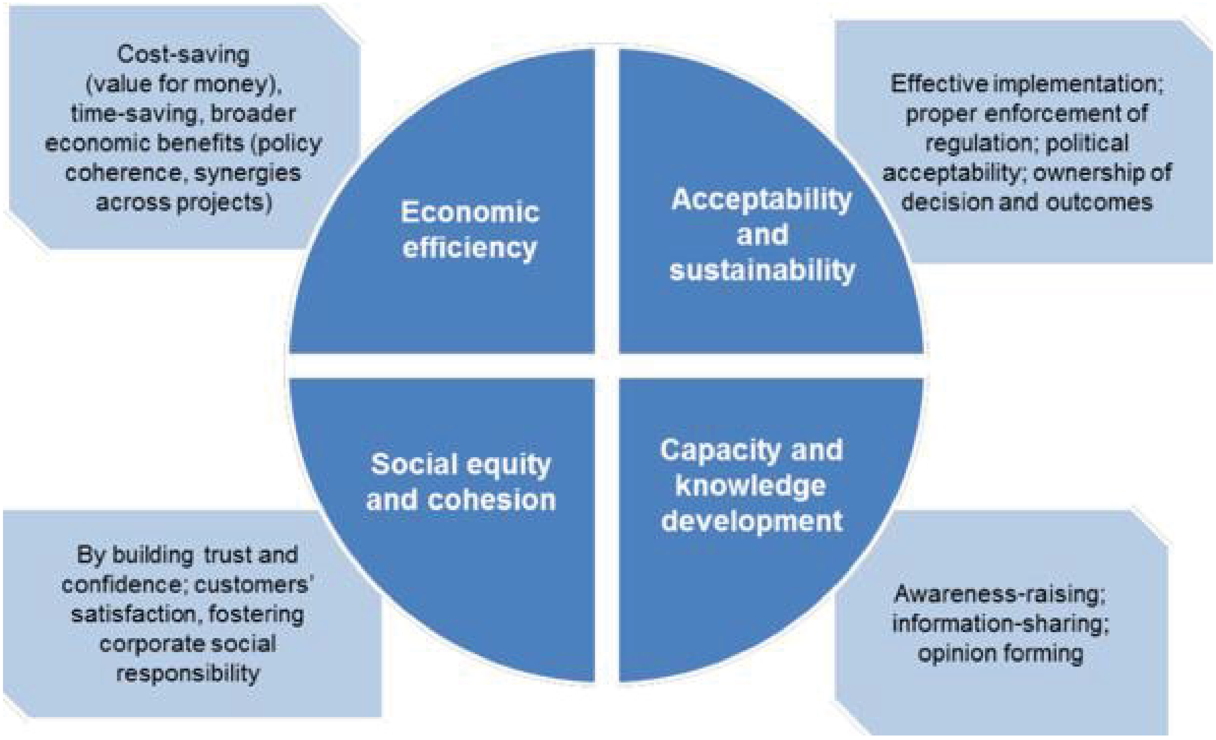
FIGURE 13 – STAKEHOLDERS ENGAGEMENT



Source: Guest *et al*. (2009)

Thereafter, in order to have an adequate collaborative engagement between the stakeholders, appropriate approaches regarding each group are basically conditioned on factors such as group's capacity (WB, 2006). Summing up, considering as satisfactory this collaborative engagement and therefore the whole process of dealing with participants, there is a tendency for the arrangement to achieve more suitable solutions at the end of the decision making process. This statement is corroborated by the OECD (2015b), which summarizes and highlights the benefits of the stakeholder engagement (Figure 14).

FIGURE 14 – LONG-TERM BENEFITS OF STAKEHOLDERS ENGAGEMENT IN WATER GOVERNANCE



Source: OECD (2015b).

In fact, the OECD (2015b) have been encouraging governments worldwide; in order to design and implement reliable and efficient water governance programs, multi-stakeholders have to be articulated and their concerns considered in the decision making process in water management. Still, the term governance in water can be spread to other treatment systems, as the same report adds (OECD, 2015b).

Illustrating the decision making participation approach, Chamberlain *et al.* (2014) have invited participants to take part even in the definition of the criteria within the decision making assessment applied on their research. The same authors have also supported participants' collaboration, and thereafter have pointed out that the DMA process should consider aspects of transparency and comprehensibility of all the people involved. This view also appeals that the process should be accessible and easy to operate for all collaborators involved in the decision content.

According to the OECD (2015b), and summarized by Akhmouch and Clavreul (2016), the benefits of having the cooperation of the participants can be defined in four categories: (i) acceptability and sustainability in terms of adequate implementation of water policy and projects; (ii) capacity and knowledge development emanating from raising greater awareness and specially from sharing information; (iii) social equity and cohesion, which is related to trust and confidence, amongst other factors; and (iv) economic efficiency, which is basically related to cost and time savings.

2nd - Defining indicators and performances measures

The second step is defined as to select the set of objectives, or so-called indicators, and the evaluation criteria. According to Gregory *et al.* (2012), given the concerns highlighted in the previous step, the challenge is to achieve a set of fundamental objectives and associated performances measures. Therefore, the discussion turns to define specific metrics, grades, and categories for assessing and reporting the effects of alternatives on the indicators selected.

Although the importance of gathering participants' information and to define indicators based on their concerns might be relevant (GREGORY *et al*., 2012; CHAMBERLAIN *et al*., 2014; LIENERT *et al*., 2016), it is still consistent to designate a set of the most commonly used indicators established as depicted in other researches (MUGA; MIHELCI, 2008; VENKATESH *et al*., 2014).

It is important to discuss that there are different possibilities to define this set of indicators. For instance, in the method depicted by Balkema *et al.* (2012), the selection of the set of indicators was made by reproducing exactly as used in another research. Another possibility is related to the availability of the measurements of the indicators (KALBAR *et al.*, 2012). In fact, it is noticeable that further data of the indicators from the selected alternatives are necessary in both cases.

To illustrate this point, there are some indicators widely used in decision making processes in the field of choosing WWTS. For instance, Kalbar *et al*. (2012) stated that in order to select the most appropriate WWTS alternative, it is important to consider specific indicators such as efficiency, reliability, sludge disposal, soil characteristics, environmental impact, implementation and operating costs, sustainability and simplicity, all of them related to the WWTS alternatives. Finally, the same authors have also highlighted that the features of weighting and normalizing also appear as important procedures specifically in environmental engineering decisions.

Turning now to the groups of chosen indicators, according to Rodriguez-Garcia *et al*. (2011), several different Spanish WWTS were compared by using diverse indicators within the life cycle assessment process. Those indicators were eutrophication and global warming potentials as environmental ones, and only implementation costs as economic. Nogueira *et al*. (2009) also aim at the assessment of economic and environmental indicators to define the most suitable conventional, or on-site WWTS solutions. However, the latter authors focused on the analysis of energy savings in the main comparison.

In light of the performance measures, the comparison criteria in terms of environmental and economic indicators, several lines of evidence suggest that the strategy is to use absolute removal efficiencies and cost values, respectively, by volume of wastewater treated (NOGUEIRA *et al*. 2009; HERNÁNDEZ-SANCHO, 2010; RODRIGUEZ-GARCIA *et al*. 2011; VENKATESH *et al*., 2012; GARRIDO-BASERBA *et al*. 2016). Except for the use of absolute costs values for economic indicators, this study adopts the performance measures discussed by Silva *et al*. (2014), who divided removal efficiencies in classifications in order to be more instructive within the decision making analysis.

Summing up, there seems to be some evidence to indicate that without some basic sustainable dimensions, for instance economic and environmental indicators, the information obtained from the decision making analysis may not provide reliable and acceptable results. It is in this view that this study intends to provide a new perspective by inserting social indicators.

3rd - Developing alternatives

Summing up, the third step can be described as the establishment of the real alternatives, or options, with respect to different priorities across the selected scenario and criteria. According to Gregory *et al*. (2012), there are important questions that have to be made in order to perform this step properly, for instance, “what constitutes a good alternative, and how to generate and then structure a good set of alternatives”. Moreover, the authors argue that in the environmental management contexts the alternatives are usually complex sets of engineered structures that in some cases need to be created. In this view, they conclude that the development of creative alternatives, which need to be undoubtedly available for the selected scenario, should also concern and respond to the defined indicators.

On one hand, although Conati *et al*. (2012) have focused their research on running and evaluating an interactive tool, more than selecting the most suitable alternatives (with non-technical approaches) given a set of different indicators, they have used a suggested tool in a way similar to that of this study. In summary, they have carried out a number of ten random available alternatives in a study that uses DMA and an interaction tool.

On the other hand, studies that acknowledge technical subjects, and specifically regarding the choice of WWTS through DMA, use representativeness of the systems in their scope (MOLINOS-SENANTE *et al*., 2014). On the same vein, Garcia *et al*. (2013) contemplate in their analysis the knowledge of three common WWTS to perform the comparison of the alternatives and then to select the most suitable one.

Other researches have focused on the investigation of the comparison between ecotechnology-based treatment systems, in decentralized and on-site scenarios (TANNER *et al*. 2012, NOGUEIRA *et al*., 2009). Rodriguez-Garcia *et al*. (2011) have adopted in their methodology the criteria for selecting WWTS based on the quality standards of the European directives and regulations.

Overall, the literature has shown that the criteria for the classification of the systems that will be encompassed in the comparison processes may diverge between themselves. Additionally, although there is a relatively small body of literature with reference to details about the principles of how to pre-select alternatives in a range of several available and well-known alternatives, this concept should be a fundamental part of the decision making process and the content of WWTS.

Therefore, given the lack of criteria with respect to this concept, the material and methods of this study have presented a tool and a subsequent methodology that intends to assist the achievement of an adequate preliminary definition of WWTS alternatives.

4th - Estimating performances

According to Gregory *et al*. (2012), this technical task should be undertaken by specialists, since the performances of the measures need to be properly estimated and it is fundamental for the success of the analysis. In this view, the specialists, or also called experts (generally natural scientists, economists, engineers, etc.), need to build a common understanding of the best available information regarding the defined indicators.

Typically, there is a large number of published studies that focus on the establishment of the performances by using modelling (Gallego *et al*. 2008; Zonta *et al*., 2012 and Venkatesh *et al*., 2014), collecting lab analysis data from pilot project or existing systems (Nogueira *et al*., 2009; and Kalbar *et al*., 2012), or even from literature reviewing (MASSOUD *et al*., 2009; MOLINOS-SENANTE *et al*., 2010; RODRIGUEZ-GARCIA *et al*., 2011; BALKEMA *et al*. 2012 and HAMZA et al. 2016).

In summary, the fourth step aims to estimate performances, with regards to the alternatives and the indicators developed, which is generally made by local or traditional knowledge holders, literature reviewing and observation in existing alternatives.

5th - Evaluating trade-off and selecting solutions

Summarizing, the fifth step aims to evaluate the participants' preferences, given the different weightings obtained for each objective previously defined. The response would come as a single alternative, or a set of alternatives, that achieves an adequate balance across multiple indicators.

Moreover, the evaluation process involves a value-based judgement on the defined indicators, and hence on the hierarchy mechanism to obtain the most suitable alternative, or alternatives. A number of studies have postulated a convergence in the application of tools to achieve favorable outcomes.

In this view, there are several ways to implement that. Several computer tools that use different approaches in their usability have been created (GREGORY *et al*., 2012). The authors add that generally the formal multi-attribute methods can be used to bring clarity, consistency, and transparency into the decision making. Although the number of available options to perform the evaluation assessment is extensive, Conati *et al*. (2014) highlight the lack of proposals that use interactive visualization, especially allowing the trade-off analysis.

6th - Implementing, monitoring and reviewing the process

The emphasis of this step is on the promotion of the capacity of the decision making process to manage better decisions in the future. It might be accomplished by identifying mechanisms and monitoring outcomes, which might improve future decisions in the same field of study.

3.3.2 Computer Tools in Decision Making Analysis

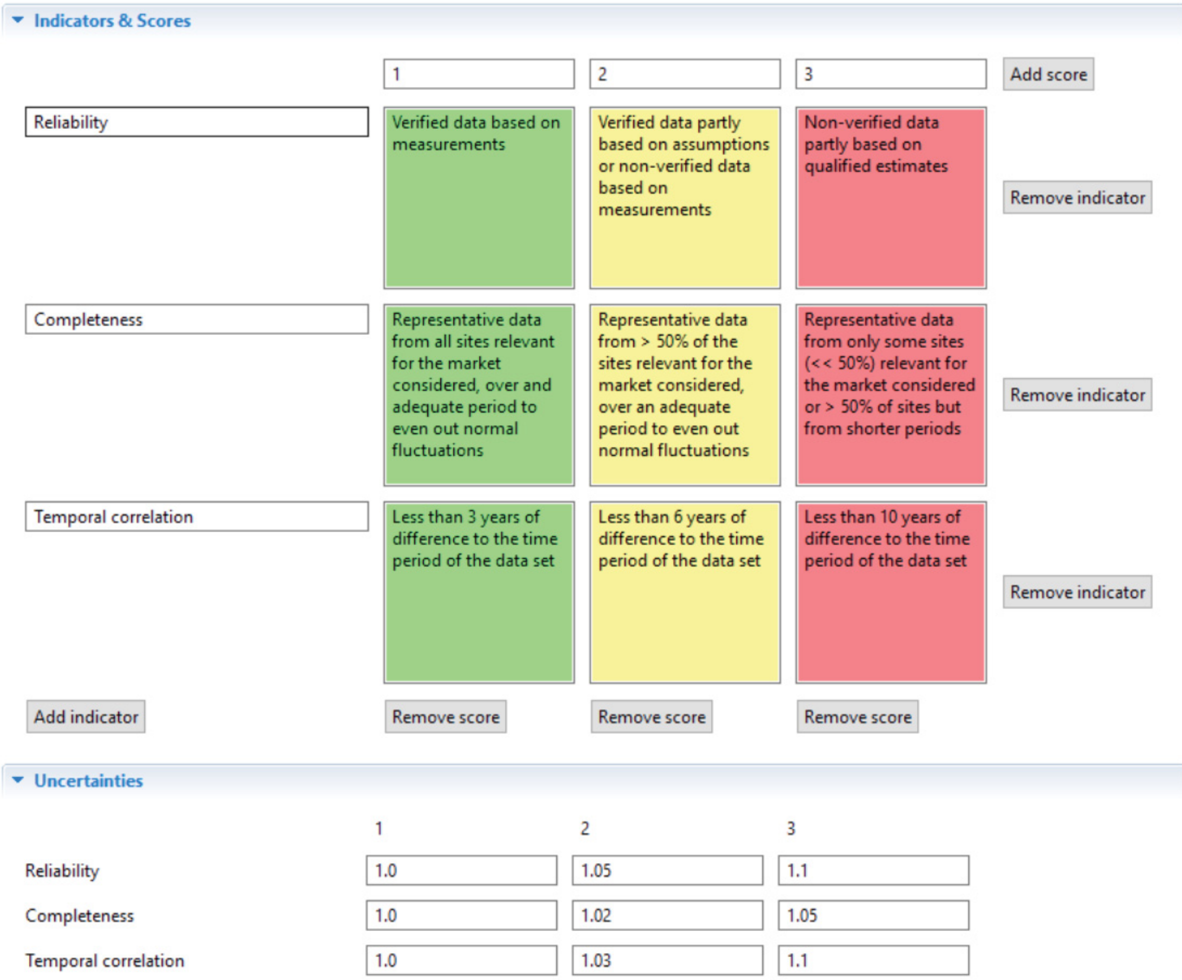
A large and growing body of literature has applied tools within DMA to select the most suitable alternatives in different decision concepts and in distinct scenarios including environmental approaches.

Some models are widely recognized, such as those cited by Kalbar *et al*. (2012): Electre, Promethee and TOPSIS. The authors have achieved substantial results by applying a decision making tool in the field of wastewater treatment into a region which lacks basic needs in India, and by evaluating which WWTS alternative suits better in different scenarios. In addition, Venkatesh *et al*. (2014) also demonstrate the effectiveness and usefulness by applying a similar decision support tool and pursuing the impacts of resource flows in urban water and wastewater systems.

The life cycle assessment approach, one of the freely available open tool, might be accessed in www.openlca.org. According to OpenLCA (2018), the data analysis can be assessed by evaluating matrices in three levels. Firstly, in terms of general data quality only for documentary purposes – i.e., not used for calculation. Secondly, as to the expected quality of the data of exchange in a process. In this scenario, it is used for calculation purposes. Thirdly, for data quality related to social aspects.

Figure 15 shows the matrix structure of a simulated OpenLCA application, wherein it is possible for the user to input their own data or also existing data. Additionally, uncertain values in terms of the decision content can also be calculated.

FIGURE 15 – MATRIX FROM THE OPENLCA TOOL



Source: OpenLCA (2018).

Indeed, the application of the OpenLCA related to WWTS approaches is found in recent researches (DUBCOVÁ et al., 2017; LI; FENG, 2018). However, in spite of the fact that the software permits the assessment of the analysis in terms of the three main aspects of sustainability (e.g. economic, social and environmental), it has been applied separately as in the cases of the cited studies. They have focused on environmental impacts rather than on the integration of the three aspects.

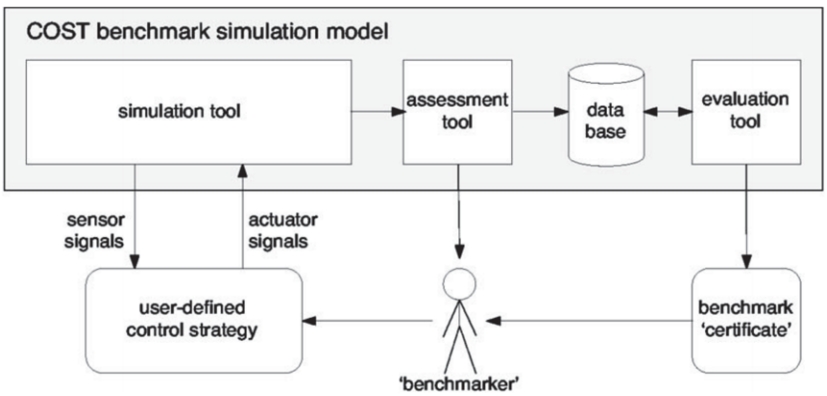
A specific computer tool that has direct connection with the definition of WWTS alternatives, namely 'Capted-Works', was firstly reported by Wrigh *et al.* (1988), Hydromantis (1985a) and Hydromantis (1985b). It is still updated and commercialized by Hydromantis – Environmental Software Solutions Inc., and according to Hydromantis (2017), the Capdet-Works basically consists in a computer assisted tool for designing and evaluating different WWTS.

Therefore, the cited tool is able to provide a preliminary design of several WWTS configurations, which comprehends in its process library more than 60 units in operations (HYDROMANTIS, 2017). Additionally, the main incorporated indicators include estimative of costs and performances needs within its analysis. Finally, one of the main features highlighted in Hydromantis (2017) is that the user can "simply drag-and-drop unit processes to build a plant schematic" to further obtain that information. Summing up, the procedure proposed by Wrigh *et al*. (1988) by using the Capdet-Works has found to be applicable for different WWTS over a wide range of flows.

Another tool that incorporates WWTS modelling was developed between 1998 and 2004. As described in Alex (2008), the benchmark tools for simulation-based evaluation was firstly focused on activated sludge process plants. The COST benchmark tool was originally defined as "a protocol to obtain a measure of performance of control strategies for activated sludge plants based on numerical, realistic simulations of the controlled plant" (JEPPSSON; PONS, 2004).

As reported in Jeppsson and Pons (2004) and COST (2018), many diverse tools were developed since the beginning of the first version of the tool, amongst them, the COST Action 682 and 624. The 624 version can be freely downloaded from http://www.ensic.inpl-nancy.fr/COSTWWTP and Figure 16 shows the principle of the COST Action.

FIGURE 16 – FLOWCHART OF THE COST BENCHMARK MODEL



Source: Jeppsson and Pons (2004).

Additionally, the Benchmarking Simulation Models (i.e. versions BSM-1 and BSM-2) are other developed versions of the benchmark body group that can be dowloaded from http://apps.ensic.inpl-nancy.fr/benchmarkWWTP. Specifically, both BSMs versions incorporate a more technical approach than the COST ones and have been featured and improved under the management of IWA task group on Benchmarking of Control Strategies for WWTPs.

Moreover, the main objective of the cited group is to elaborate models and simulation tools that include the analysis and evaluation of long-term control of the most typical unit processes within a WWTS – e.g., primary, secondary, and sludge treatment IWA (2018a). The BSM tools consider the design of five-compartment reactors contemplating anoxic zone and a secondary settler (IWA, 2018b). It involves a technique to control the dissolved oxygen level in the final compartment and the nitrate level in the last anoxic compartment. Summing up, the BSMs tools aim to optimize an activated sludge process by expanding the expertise of microorganisms' internal processes by building an integrated plant control based on the entire wastewater system.

The BSM tools have shown adequate results in terms of comparing diverse plants layout, simulation model, influent loads, test procedures and evaluation criteria, always focusing on ASP. Although, there is a lack in defining different WWTS alternatives and configurations – e.g., WSP and UASB. Additionally, the tool does not allow the access to user's preferences and bias regarding the defined indicators that are part of the DMA process.

Now turning to another decision making tool, a relevant one was developed by Oliveira (2004), which was still available by the time of the development of this study. The ETEx tool is also related to the definition of WWTS alternatives and it is available on the ETEX (2018) website. The model was developed based on decision making context to support the choice of a suitable WWTS in terms of economic and environmental aspects. As a final product, the tool elaborates the design of six alternatives, providing their respective implementation and operational costs.

Although the ETSx tool can be considered a useful model given the ample intrinsic data used within the modelling process, and especially by the transparency and quality of the resulted WWTS for Brazilian scenarios, it does not acknowledge important factors that are discussed in this research. Firstly, it does not consider the social group of indicators (e.g. odor, staffing requirements, amongst others). Secondly, it does not allow the collection of preferences given by different groups of participants, in particular the community, and hence it does not produce the visualization of their predilection. Finally, it does not comprehend the majority of the features that could be integrated and presented in a tool, for instance, user-friendliness, visualization and interactiveness.

In addition, there are other tools used that were developed and tested by many other researchers, for instance: SANEX (LOETSCHER; KELLER, 2002), Life Cycle Assessment (MUGA; MIHELCIC, 2008), WAWTTAR (FINNEY et al. 2009); Answer Set Programming (AULINAS *et al.*, 2011), Scenario Planning (SCOTT *et al.*, 2012), LineUp (GRATZL, *et al.,* 2013), Multi Attribute Value Theory (MARTTUNEN *et al.*, 2015), SWING (LIENERT *et al.*, 2016), and others, which were also applied in the environmental engineering field.

As previously stated, many recent studies have shown that different types of tools have been developed and applied in the field of water management, specifically regarding wastewater treatment infrastructure. Nevertheless, as described by Conati *et al*. (2014), they have focused on visualization processing that use a non-interactive manner, for instance bars and radar charts.

As shown earlier, there are many different computer program tools popularized in decision making processes to guide de definition of the most appropriate WWTS alternative. However, it seems that models and their domain of application grow in complexity, the analysis of the resulting rankings become very challenging.

Conati *et al*. (2014) add that some studies have considered that users' characteristics have an important impact on visualization effectiveness. Hence, it suggests that "visualizations could be designed to better fit each user's specific needs". In this view, some researchers have been examining analytically decision making tools and have concluded that the ValueCharts is one of the most effective tools, especially for non-technical users (BAUTISTA; CARENINI, 2006; YI, 2008, CONATI *et al*., 2014), given both interactive and visualization components.

Table 9 presents the features of the most relevant tools mentioned in this subsection. Firstly, it depicts if they allow the managers to input different types of indicators and alternatives. Secondly, it characterizes if the tools are capable of being used by non-expert's groups of participants. Thirdly, if they have considered weighting analysis and restatement preferences within their structures. Finally, if the tool considers important features such as visualizing and interactiveness tools.

TABLE 9 – SUMMARY OF RELEVANT TOOLS USED IN COMPLEX EVALUATION DECISIONS

Tool's name	**Open to insert indicators and alternatives**	**Does not require advanced technical background**	**Allows weighting and preferences restatement**	**Considers both visual and interactive features**	**References**
Electre	-	✓	-	-	Kalbar *et al*. (2012)
Promethee	✓	-	-	-	Kalbar *et al*. (2012)
TOPSIS	-	-	✓	-	Kalbar *et al*. (2012)
OpenLCA	✓	✓	-	-	Dubcová et al. (2017) and Li and Feng (2018)
Capdet-Works	-	-	✓	-	Wrigh *et al*. (1988) and Hydromantis (2017)
Benchmarks	✓	✓	-	-	Alex (2008); Jeppsson and Pons (2004); COST (2018) and IWA (2018b)
ETEx	-	✓	✓	-	Oliveira (2004) and ETEX (2018)
ValueCharts	✓	✓	✓	✓	Bautista and Carenini (2006); Yi (2008) and Conati *et al*. (2014)

Sources: Cited within the table.

Finally, the ValueCharts has a quite similar framework to the LineUp. It has demonstrated reliability and feasibility when analysing outcomes and afterwards trade-off processes (CHAMBERLAIN *et al.*, 2014). The next subsection discusses specifically the characteristics of the ValueCharts, and why it was chosen for this research.

3.3.3 ValueCharts tool

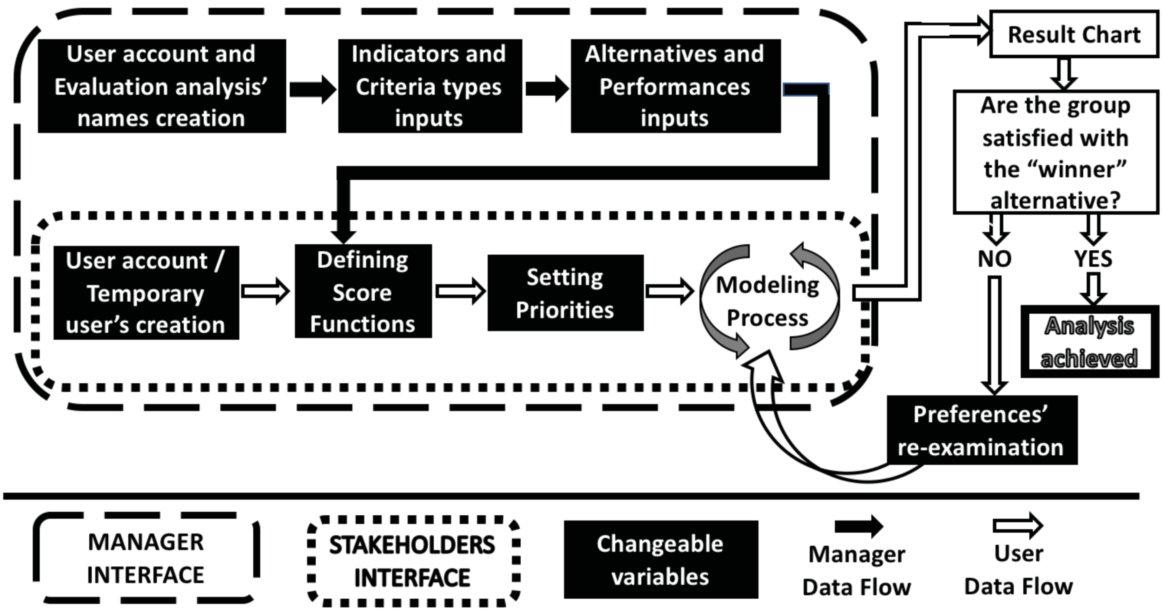
The ValueCharts tool can be defined as both ”open-source” and "open free” web model/tool. It is “open-source” since the code is freely available for viewing, downloading and changing by anyone at https://github.com/ValueChart/WebValueCharts. The features of the application can be freely used or simulated over the internet by simply accessing the url http://valuecharts.cs.ubc.ca. Both the manager of the decision making analysis and the participants of the process can access the tool.

According to Carenini and Loyd (2004), Chamberlain *et al*. (2014) and Lallé, *et al*. (2016), the ValueCharts is a set of visualizations and interactive techniques targeted to support decision making analysis. In other words, it is “an interactive visualization to support decision makers in preferential choice, namely selecting the best option out of a set of alternatives characterized by a variety of attributes/criteria” (LALLÉ *et al*., 2016).

Chamberlain *et al.* (2014) reported that by using the ValueCharts tool, aspects of participation, transparency and comprehensibility can be more easily achieved in a decision making process.

Moreover, both managers of the analysis and users make the application method of the ValueCharts tool. The main difference in the use is that the manager is responsible for creating the process, wherein the alternatives, indicators and performances are inputed. Figure 17 shows how the data flow works within the ValueCharts tool.

FIGURE 17 – VALUECHARTS' SCOPE



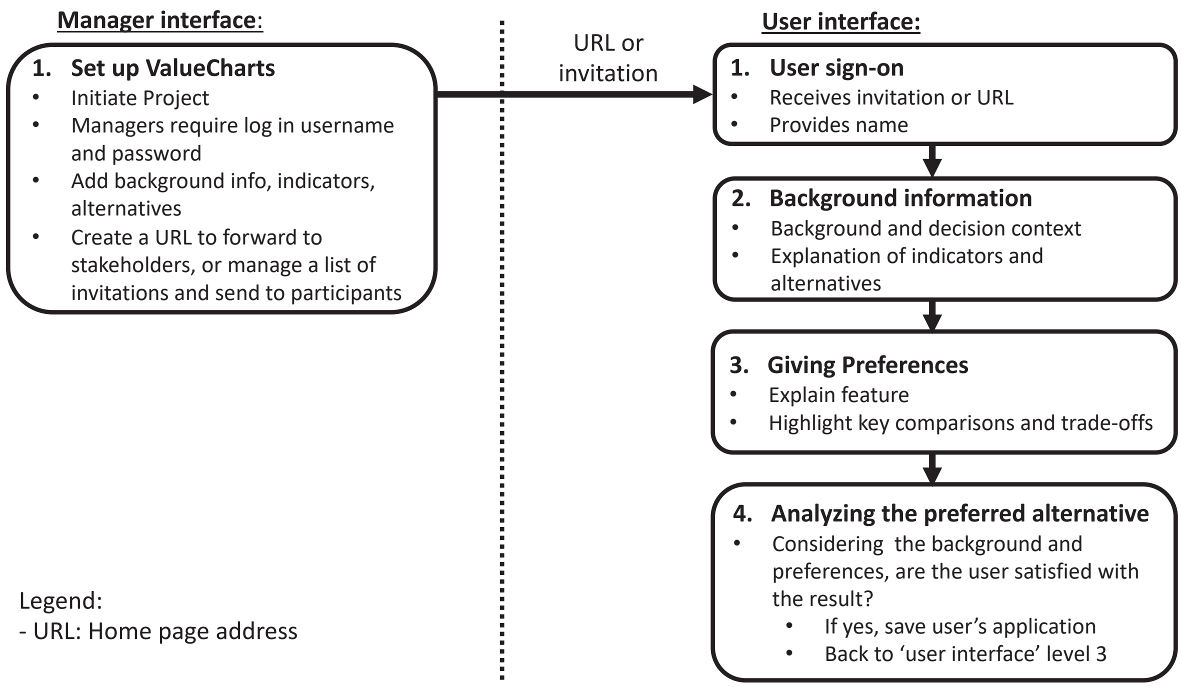
SOURCE: The author (2017).

According to Figure 17, the ValueCharts can be concisely depicted as a tool that intends to perform the comparison process of several different alternatives, by providing results considering each participant's concerns. Additionally, the tool facilitates further trade-offs of the indicators' preferences in a featured simple interface.

Similarly, Chamberlain *et al*. (2014) found that the main feature of the ValueCharts is to achieve effectiveness by providing results and combining “simple visualization and interactive techniques to support the decision maker in analysing their own preference model and its application to a set of alternatives”. A broader perspective was adopted by Wongsuphasawat *et al*. (2012). These authors have successfully tested the tool as a component of a sophisticated interface for querying event sequences.

Figure 18 presents a practical sketch of application of the ValueChart with a great number of participants, a municipality for instance. In this case scenario, it may become necessary to have a plan to reach a considerable number of participants of the decision process.

FIGURE 18 – PRACTICAL STRUCTURE FOR A VALUECHARTS APPLICATION



SOURCE: The author (2018).

Turning now to models of the cited tool, linear ones have been widely used in decision making tools to support the decision maker rank available alternatives. In this view, the modeling process of the ValueCharts tool basically consists in converting ranks into weights based on the rank order centroid model (MUSTAJOKI, 1999).

Musiyarira et al. (2012) describe how to use the model in order to obtain the final scores, as depicted in equation 1:

$$\mathrm{V}(A_i) = \sum_{k=1}^{K} \omega_k \; v_{ik}, \qquad i = 1, \ldots., m \qquad \text{Equation 1}$$

where V is the overall multi-attribute value for each alternative (A_i = 1, 2, …, m). The ω_k are the weights of the k^{th} indicator and K are the total number of indicators within the analysis (obtained from Equation 2), while the v_{ik} are the performances associated with the i^{th} alternative and k^{th} indicator, perceived by each user.

The weight ω_k is obtained through the application of the equation:

$$\omega_k = \frac{1}{K} \sum_{l=k}^{K} \frac{1}{l} \qquad \text{Equation 2}$$

where l is the given order of a specific k^{th} indicator.

The following four tables intend to exemplify with a hypothetical analysis how the cited rank order centroid model works. Firstly, Table 10 presents three fictitious alternatives (A, B and C) and their inherent performances of assumed indicators (X, Y and Z).

TABLE 10 – HYPOTHETICAL GROUP OF ALTERNATIVES AND PERFOMANCES

Alternatives (A_i^{th})	**Indicators' performances**		
	X	**Y**	**Z**
A	10	30	60
B	40	50	40
C	80	70	30

SOURCE: The author (2018).

In Table 11 it is depicted an assumed performances' values given by hypothetical users (USER_1, USER_2, USER_3). They are values between 0 and 1, in which 0 is given to the correspondent lowest performance while 1 is provided to the highest preferred one, of each indicator. The intermediate values are also associated with weights, as seen in Table 11.

TABLE 11 – EXAMPLE OF ASSUMED USERS' PREFERENCES

Perfomances values of the X, Y and Z indicators)	Users' preferences v_{ik}		
	USER_1	USER_2	USER_3
X (10, 40, 80)	(0, 0.5, 1)	(1, 0.5, 0)	(1, 0.5, 0)
Y (30, 50, 70)	(0, 0.5, 1)	(0, 0.5, 1)	(1, 0.5, 0)
Z (60, 40, 30)	(0, 0.5, 1)	(1, 0.5, 0)	(0, 0.5, 1)

SOURCE: The author (2018).

Subsequently, Table 12 details the hierarchy in terms of relevancy also given by the users between those same indicators. Additionally, it presents the correlated weights through the application of equation 2.

TABLE 12 – USERS' SUPPOSED HIERARCHIES

Indicators	Users' Hierarchies					
	USER_1	$\omega_{k^{th}}$	USER_2	$\omega_{k^{th}}$	USER_3	$\omega_{k^{th}}$
X	1st	0.6111	2nd	0.2778	1st	0.6111
Y	2nd	0.2778	1st	0.6111	3rd	0.1111
Z	3rd	0.1111	3rd	0.1111	2nd	0.2778

SOURCE: The author (2018).

Conclusively, the final scores of each alternative from the equation 1 application is shown in Table 13.

TABLE 13 – FINAL SCORES OF THE HYPOTHETIC EXAMPLE

Alternatives (i^{th})	Final individual scores $V(A_i)$ in %			Averages scores (%)
	USER_1	USER_2	USER_3	
A	0	39	72	37
B	50	50	50	50
C	100	61	28	63

SOURCE: The author (2018).

Finally, the ValueCharts tool was developed by a computer science group at the University of British Columbia (UBC), at the time of this research's progress. Considering the cited advantages (for details see Table 9), this study uses the ValueCharts tool in the 5th step of the adapted SDM instrument. In other words, in the alternatives' evaluation step.

3.4 DISCUSSION REGARDING THE BLANK GAPS OF THE LITERATURE REVIEW

Acknowledging the background provided in the first section of this chapter, it is possible to comprehend the reasons why haphazard urbanization becomes a problem in the developing world, especially concerning the lack of SS systems in peri-urban areas. It can be learned that there is no indicative that this trend will reverse or decelerate. Thus, more people in the next years will probably face poor coverage of basic infrastructure, specifically regarding sewerage networks and availability of WWTS.

Resuming the section related to WWTS, the concepts concerning sewage treatment have helped to create a positive perception. In other words, there are developed technologies within the literature review that contemplate sustainable characteristics and could be suitable for the scenario selected.

Furthermore, considering conceptual approaches absorbed after the second and third sections, there is another fundamental assumption that emerges. Even though there are many different available WWTS solutions that could easily provide treatment and perhaps solve the lack of SS, one of the main problems is concerning specific aspects related to decision making processes.

Despite the existence of several different decision making analysis systems and tools supporting the decision making processes, which somehow consider widely used characteristics (e.g. affordability, decentralization, efficiency, sustainability, amongst others) in their evaluation processes, there is a need for such a methodology that contemplate a group of sustainable concepts. It has to contemplate an integrated format that considers internal tools acknowledging specific features (e.g. user-friendliness, visualization and interactiveness).

In this view, this study has acknowledged a specific decision making process, namely Structured Decision Making (SDM), which was adapted in order to allow the application within the defined scenario, that encompasses peculiar tools (namely PS-WWTS and ValueCharts) within the application method.

Another concept within the definition of the most appropriate WWTS is concerned to sustainability in terms of balancing its three basic dimensions (i.e., economics, social and environmental). According to Rodriguez-Garcia *et al*. (2011), it is well recognized that when considering a sustainable WWTS system, the analysis should embrace all of those cited dimensions. Notwithstanding, Garrido-Baserba *et al*. (2016) have argued that previous researches, and also decision-makers, usually do not take account of the social aspect.

Using the same approach, Guest *et al* (2009) have corroborated this gap by defending that in order to obtain success in the implementation of sustainable solutions, it is necessary to consider the social dimension within the decision making assessment. It reinforces the beliefs of this study in pursuing more sustainable WWTS solutions. Thus, it should consider those three cited aspects integrated, especially the social group.

In this view, it is important to state that none of the depicted appealing for sustainable characteristics could be evaluated and converted onto a decisive WWTS solution and hence immediately applied without a comparative analysis. On the contrary, it is necessary to associate principles of decision making analysis that consider different groups of participants and their concerns for achieving an adequate decision.

As stated before, despite the fact that there are many available decision making processes in the literature, the SDM has appeared as a suitable resource management. Yet, within the SDM process, there is an important obstacle when the weighting process associated with the objectives, alternatives and evaluating criteria, takes place. That brings up the importance of using computer models, or tools, to help to support DMA and its inherent gaps.

Moreover, in spite of the importance of performing all six steps of the original SDM process (for details see subsection 3.3.1), it is relevant to highlight that the sixth step (implementing, monitoring and reviewing the process) will not be assigned equally as presented by Gregory et al. (2012) in this research. As an expected result within the sixth step defined in this adapted SDM, the interviews and questionnaires applied have intended to obtain additional knowledge regarding the whole application of the process, and especially of the proposed tools to be incorporated in future studies.

Summing up, this research intends to fill those blanks regarding the use of DMA and resource tools to select WWTS alternatives, which can be enumerated as follows:

- There are some decision making instruments (e.g. life cycle assessment, benchmarking, and others) that permit analysis of the three pillars of sustainability: economic, social, and environmental. Nevertheless, there are limited studies that incorporate the integration of those aspects within the analysis;

- Characteristics (e.g. user-friendliness, visualization and interactiveness) are generally ignored within the evaluation step;

Finally, there is a relatively small body of literature that proposes achievable mechanisms that merge all those mentioned gaps. Additionally, they rarely convert the results into reliable and sustainable WWTS alternatives for peri-urban communities. In order to reach the previous defined objectives, and thus seeking to fill those blanks, the next chapter presents the material and methods components regarding how it was accomplished.

4 MATERIAL AND METHODS

4.1 INTRODUCTION

This dissertation can be classified, according to the concepts of Gil (2002), as an exploratory research since the main objective is familiar with the problem. According to Yin (2005), generalizations of a topic of this nature are analytical rather than statistical.

On the same vein, according to Lakatos and Marconi (2003), the exploratory study assists the development of hypotheses, increasing familiarity and clarifying the researcher's concepts with the research problem.

Basically, there are three conditions to use each type of methodological strategy for chosing the research method (YIN, 2005). The first is related to the type of question of the proposed research. Secondly, the researcher's control over current events. Finally, the focus' degrees on contemporary events in opposite to historical events.

This research has mostly contemplated those conditions by acknowledging an applied study. Specifically, by performing surveys within the application which are defined by Robson (1993) as strategies not associated with practical information. For instance, questionnaires composed entirely or largely of fixed questions. In addition, the author adds that the "survey" has fundamental characteristics for selecting a sample. In other words, it is adequate for this research considering the possibility of analysing the characteristics of the studied object.

Therefore, the method of this research considers two main approaches to achieve the objectives depicted in Chapter 2, namely the human perceptions evaluation and environmental engineering analysis. Even though they might be interpreted dualistically, they are connected due to their interdependency in order to seek for satisfactory results.

On the one hand, an adapted Structured Decision Making (SDM) instrument was applied towards the obtention of results related the participants' preferences. Therefore, an investigation by collecting the predilections from different actors within the community-based approach was assessed. This interaction has enabled the establishment of common interests and hence the achievement of equitable results.

On the other hand, an evaluation of different Wastewater Treatment System (WWTS) alternatives was simultaneously approached. Hence, their performances and characteristics through the investigation in academic literature was stablished. Specifically, from papers that have acknowledged data associated with the performances of the pre-defined set of WWTS alternatives.

It is important to highlight that without the integration of both aspects, the thesis would not have presented adequate and solid outcomes, since both approaches are inherently connected under the Decision Making Analysis (DMA) application.

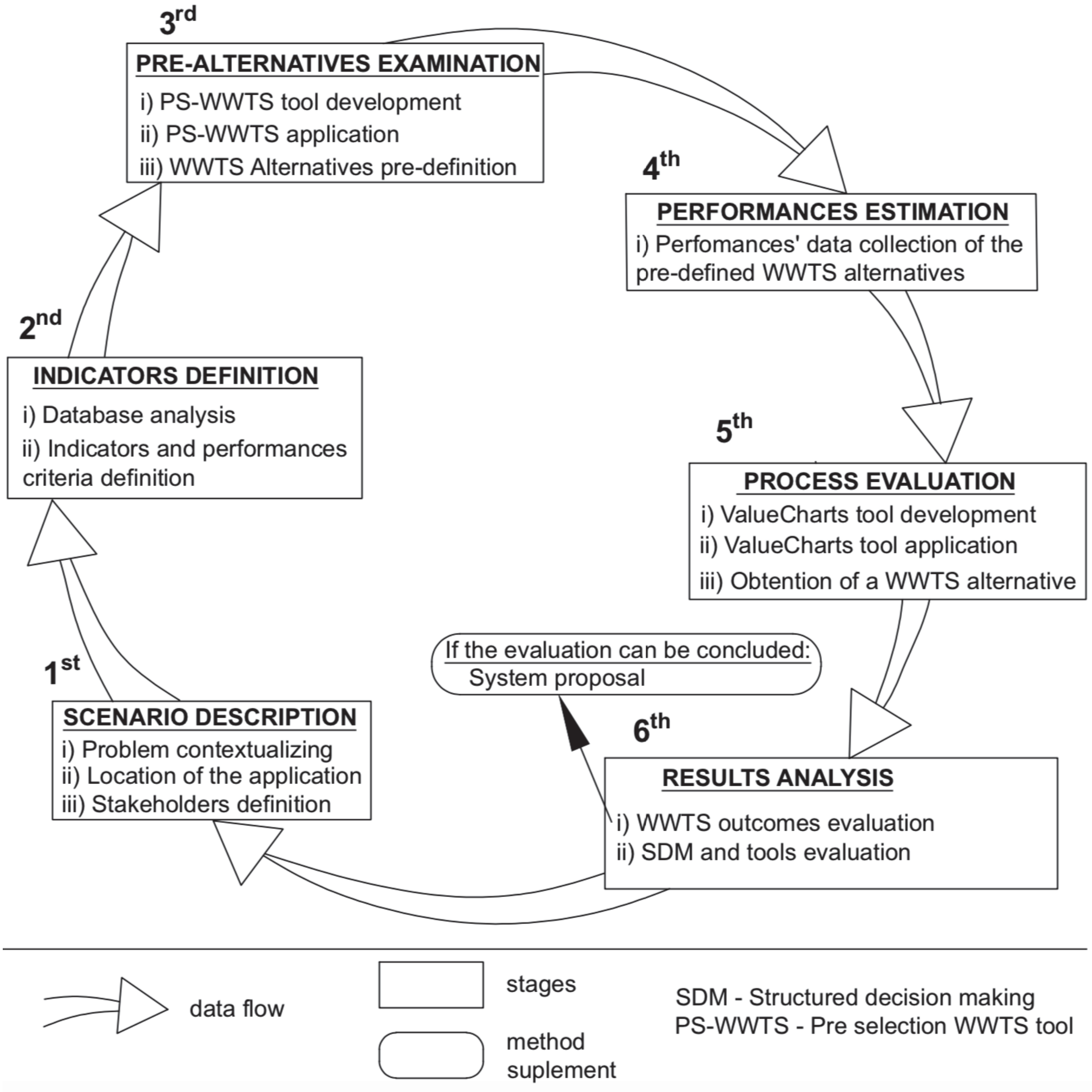
Finally, the fact that this thesis has dealt with those cited disciplines, and thus it has gone beyond traditional boarders, the research can be classified as an interdisciplinary study. In light of this view, this study needed to combine those different approaches to analyse the most suitable WWTS solution, or solutions, and then to answer the research question depicted in Section 1.6.

4.2 GENERAL STRUCTURE OF THE PROPOSED METHOD

Therefore, although adapted, the overall research's design (Figure 19) follows the steps of the original SDM methodology. It also briefly introduces each step of the process and how data collection was performed.

As it can be seen in Figure 19 and Table 14, a generic structure of a specific DMA was built for this research, the adapted SDM instrument. Its application contemplates the framework as depicted in Subsection 3.3.1. The next section explains how the steps were inserted within the applied study and also the application schemes. Hence, how the attributes of the tool have helped to evaluate suitable WWTS alternatives.

FIGURE 19 – ADAPTED SDM STRUCTURE



SOURCE: The author (2018).

From the previous structure shown, the steps can be summarized as follows:

TABLE 14 – STEPS OF THE ADAPTED SDM STRUCTURE

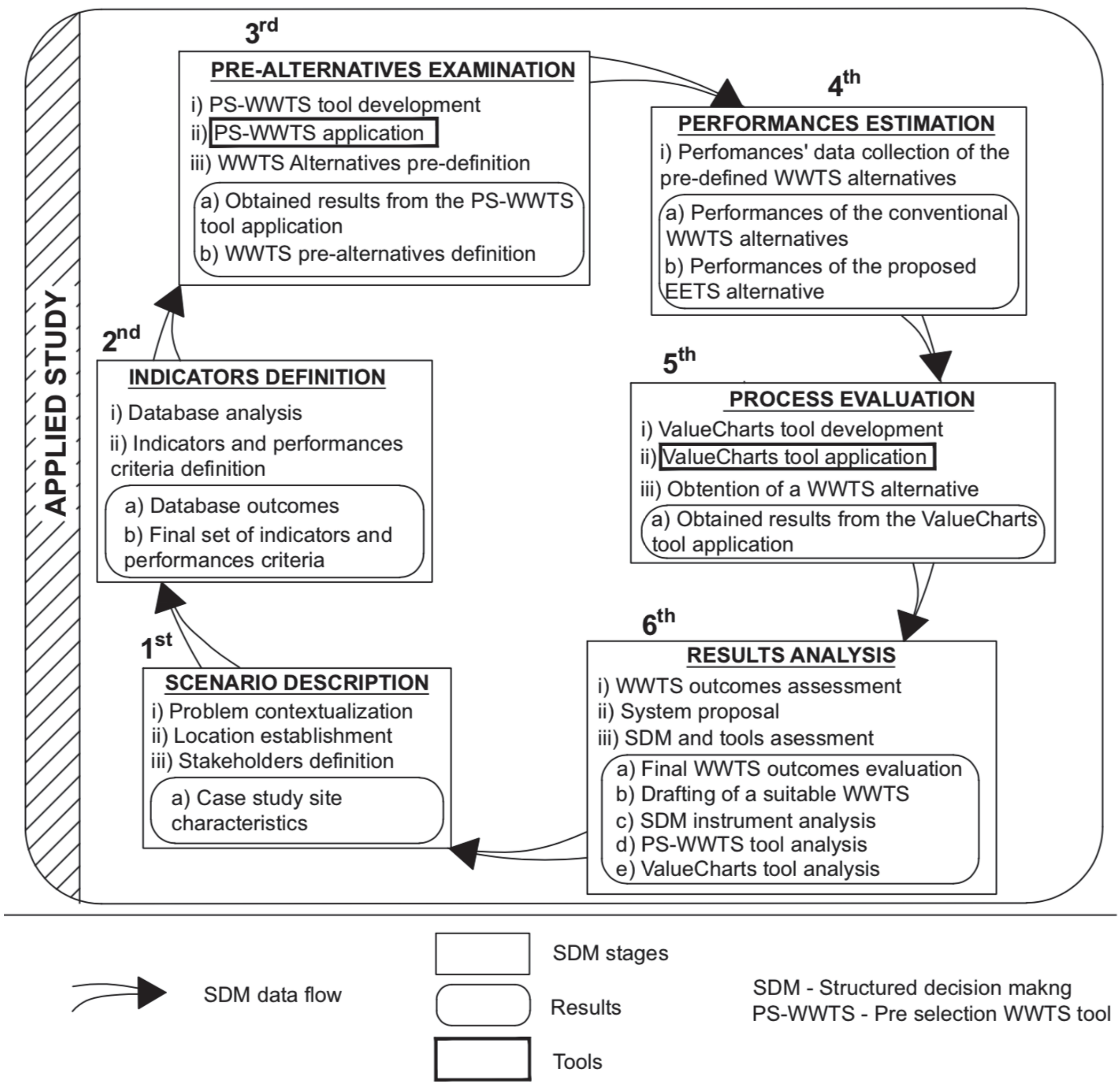
Step	Activities
1st	Definition of the characteristics of the scenario and the participants involved.
2nd	Definition of the used indicators within the decision making process.
3rd	Creation of the Pre-Selection of WWTS (namely PS-WWTS) tool and therefore in the pre-definition of WWTS alternatives.
4th	Obtainment of the performances of the pre-defined alternatives.
5th	Evaluation of the pre-defined alternatives based on the preferences given by the participants
6th	Results assessment and controlling process.

SOURCE: The author (2018).

4.3 APPLIED STUDY DETAILS

In the next framework shown in Figure 20, it is demonstrated the application of the adapted SDM instrument, by performing an applied study and also surveys (i.e. questionnaires and interviews). The order and enumeration of the steps of the generic instrument are followed and elucidated in details subsequently.

FIGURE 20 – STRUCTURE OF THE APPLIED SDM WITHIN THE APPLIED STUDY



SOURCE: The author (2018).

1st – SCENARIO DESCRIPTION

i) Problem contextualization

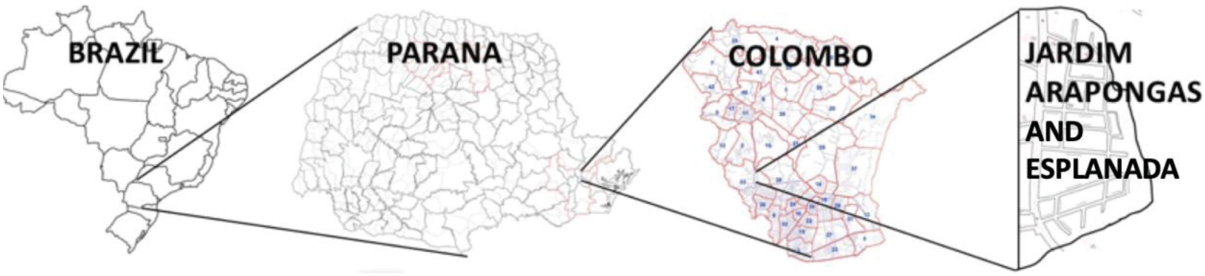
The problematic of this study was discussed in the introduction (Section 1.1) and in the literature review (Section 3.1). Summing up, it intends to apply a specific DMA in terms of application of tools for choosing suitable WWTS alternatives.

ii) Location establishment

This stage of the instrument has contemplated the definition of the chosen specific community in the applied study application. The scenario selected is related to urban sites that surround urbanized areas that lack basic sanitation infrastrucuture. Given that it is a common issue in developing countries, examples of this scenario can be found in many Brazilian municipalities.

Thus, this research has performed the investigation into the community that contemplates both areas of Jardim Arapongas and Jardim Esplanada, located within the Colombo municipality, Parana state, Brazil (Figure 21).

FIGURE 21 – GENERAL LOCATION OF THE METHOD APPLICATION



SOURCES: The author (2017)

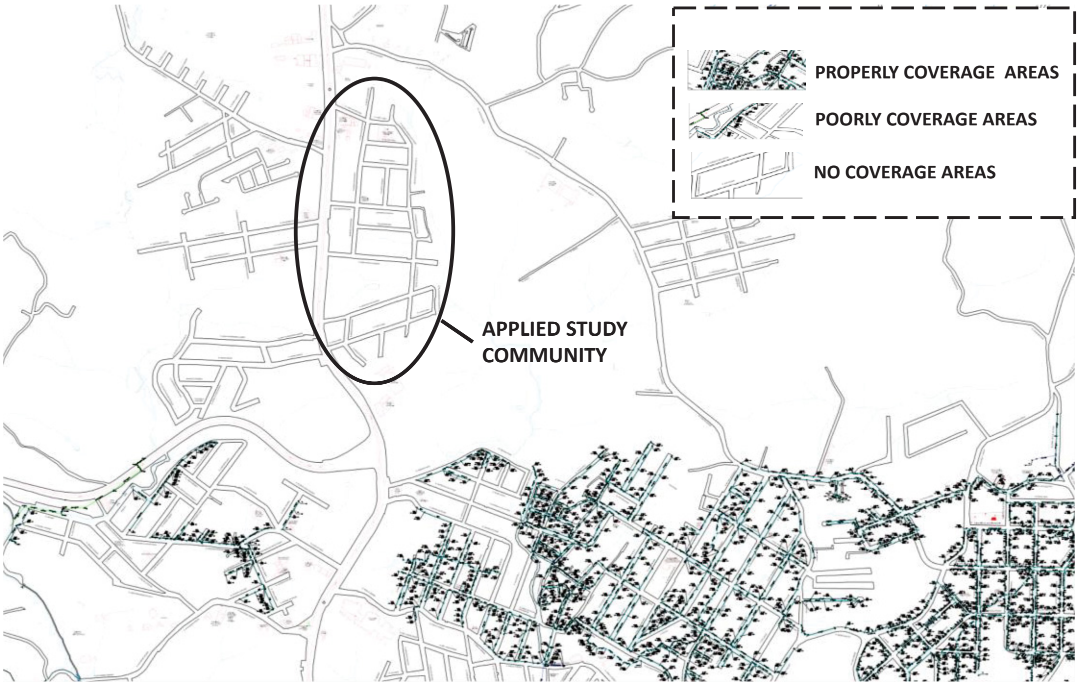
Regarding the hydrography, the Colombo municipality belongs to the High Iguaçu basin. Moreover, the defined community represents insignificantly 0.06% of the total cited basin area. However, this lack of sanitation issue can be constantly found in Brazil and it may progressively affect higher areas. Considering that, according to SEMA (2015), the High Iguaçu basin is one of the most important basins in the Parana state since it is linked to many reservoirs which supply drinking water for nearby areas, novelty DMA correlated to providing sanitation might be important to mitigate water contamination problems. Specifically, the importance of preserving that environment by providing adequate sewage collection and further treatment relies on the quality of the basin's dependent ecosystems (e.g. animals, plants, human being, etc.), and also other related activities (e.g. fishing, agriculture, drinking, recreational, amongst others).

Since there are no specifc information regarding basic infrastructure coverage in reference to the defined Colombo community, this research has performed personal visits in order to have a broader perspective of the cited community. It could be noted that the majority of the residents do not have access to proper education, public health and safety. Concerning water management, that is the access to clean water and SS, in spite of the fact that the high majority of the residents hold the benefit of accessing adequate drinking water, there is no type of proper sewage conveyment or treatment. Hence, all domestic sewage is directly discharged into a river which surrounds the households and hence the community.

According to IBGE (2010a), the total population of the Colombo municipality is around 235 thousand people, and the surface area comprehends approximately 160 square kilometers. Even though the Human Development Index (HDI) of Colombo is higher than Brazil's, 0.764 and 0.699 respectively (IBGE, 2010b), it is still low compared to the developed world, which is above 0.800. According to the same IBGE report, which is corroborated by the SNIS (2016), only approximately 54% of the whole population of Colombo has semi-adequate sanitary sewerage (SS) systems. In addition, the current municipal plan of basic SS reported that only 51.04% of the total Colombo municipality have coverage of sewage collection pipes (COLOMBO, 2016).

Showing some sanitation characteristics of the scenario, Figure 22 presents a map of the sewerage coverage of Jardim Arapongas and Esplanada, also in neighboring areas.

FIGURE 22 – SEWERAGE NETWORK COVERAGES OF THE DEFINED COMMUNITY AND ADJACENT AREAS



SOURCE: SANEPAR (2017).

The document was provided by SANEPAR (2017), which is a government company responsible for implementing and operating sewerage networks, potable water and WWTS for the Paraná state. The map also indicates different scenarios of the sewerage coverage.

iii) Participants definition

According to Brazil (2007), the responsibility for water services should rely on local, state, and federal governments concomitantly. In this view, DMA process related to SS systems should be managed by government officials. Identifying which level of government leads the process is the first action when developing a decision system.

Moreover, according to Kalbar *et al.* (2012), when defining the participants who participate in the decision analysis, different groups should engage, thus having their different perspectives. This investigation has therefore considered:

- A community group (CG) of 16 households who live in the selected area (i.e. Jardim Arapongas and Jardim Esplanada). The information was collected from the interviewed households, through the application of semi-structured interviews. They were thereafter inserted into the ValueCharts tool, providing to the community the important participation of the decision process;

- Likewise, the outcomes within the government group (GG) were collected through the application of the ValueCharts tool. As well as their opinions regarding the tools through the application of a questionnaire. The size of this group, as well as the third group (specialists), was different given its representability in the context of the scenario. The entire inquiry process has considered 5 public servants (technicians and government officials) associated with basic infrastructure and financial resources, at the municipal level. In other words, representatives somehow involved with decision making related to the issues, as highlighted in this research;
- Finally, the ValueCharts tool was applied, as well as the same cited questionnaire, within a specialist group (SG), represented by 5 technicians (civil and environmental engineers), who had background in SS field. Secondly, professors with background in sanitation were also enquired.

Thus, the results from the attributed three groups were further analysed in both particular and group perspectives. It has aimed to observe the behavior and trends of each group, and also if there were common interests when it performed the combination of each group's concerns.

Table 15 also summarizes how the evaluation was performed. In other words, it presents the inquiry method applied in reference to each group and also how the evaluation data collection regarding the opinion of the tools was achieved.

TABLE 15 – GROUP SIZES USED IN DATA ANALYSIS

Group Definition	Occupation	Inquiring format			Exclusive Group Size
		PS-WWTS	**ValueCharts**	**Assessment process**	
Community	NA (16)	NA	SI	SI	n = 16 (62%)
Government	Engineer (2)	NA	DA	Q	n = 5 (19%)
	Biotechnology (1)	NA	DA	Q	
	Administrator (2)	NA	DA	Q	
Specialist	Engineer (5)	DA	DA	Q	n = 5 (19%)

Notes: NA - Not applied, SI - Structured interview, DA - Direct application, Q – Questionnaire
SOURCE: The author (2018).

Finally, as it can be seen in Table 15, after applying the ValueCharts tool, government and specialists group were also inquired. They were required to fill out a structured questionnaire with regards to the opinion and preferences of the content of the entire SDM instrument and applied tools. In other words, the inquiries (Appendix 1) have aimed to identify if there were divergencies associated to the operation and technical features of the tool. More importantly, specific questions and the analysis of the responses to the questionnaires have intended to provide fundamental information in order to evaluate the tools in terms of their attributes, as discussed in the research question and objectives (Section 1.6 and Chapter 2, respectively).

2nd – INDICATORS DEFINITION

The next three stages within the 2nd step depict how the method has contemplated the process of the indicators' definition.

i) Database analysis

The database assisted design has considered the use of the free access to the ASCE mechanism. Researchers, such as Coffman et al. (2010) and Yeo and Simiu (2011) have used this database searching method for improving analysis in their researches. Moreover, some terms such as "indicators", "WWTS", "comparison", "evaluation", "treatment performances" were merged and hence inserted in the ASCE (2018) for accessing the database.

A subsequent assessment of the obtained set of manuscripts was achieved in order to have the complete group of indicators. Therefore, from several different ones, only a limited group of peer-review studies was selected. Those previous criteria were based on the direct correlation with the same subject of this research, that is, researches that have used DMA for comparing WWTS in different scenarios.

Afterwards, the criteria considered for selecting the final set of indicators has acknowledged importance, overlaps and similarities, quantifiable (i.e., existing data) and sustainable approaches.

Although the term sustainability have been widely related to preserving environmental resources in several researches, others have supported that sustainable WWTS alternatives are those that have the ability to balance environmental, economic and social aspects. This ability was also another relevant criterion to choose the indicators used in the SDM process.

ii) Indicators and performances criteria definition

Taking into account the list of the selected set of indicators, this study has acknowledged the definition of the performances criteria for each indicator, based on the ValueCharts' patterns (i.e., categories and continuous), as also presented in detail in Chapter 5.

3RD – PRE-ALTERNATIVES EXAMINATION

The next stages elucidate the development process of the cited tool and how the WWTS pre-definition has occurred.

i) PS-WWTS tool development

To achieve this goal, this research has developed an auxiliary tool, in which all the work related was carried out by using Microsoft Office Excel. The XML file and its usability are widely well known for it considers aspects such as ease of access in other free office suites.

The tool was prepared according to the procedure of a similar one created by Tilley *et al*. (2014), once the main aims of their tool higly match with those of this study, especially in terms of the links between the variables and the possible alternatives. However, admitting the necessity for a simple and easy to understand tool, the PS-WWTS basically consists in pre-determining WWTS alternatives after the user input three basic characteristics of the scenario.

In addition to the large set of cited conventional WWTS alternatives in Tilley *et al.* (2014), the EETS alternative was inserted into the PS-WWTS tool given its treatment processes characteristics. The proposition of including the EETS as an alternative was because it could be suitable for the scenario selected. It was hence expected that the EETS could also be pre-selected by the users of the tool (see 1st step). Indeed, as it is seen in the results and discussion chapter, the EETS was one of the chosen WWTS alternatives (for details see subsection 5.3.2).

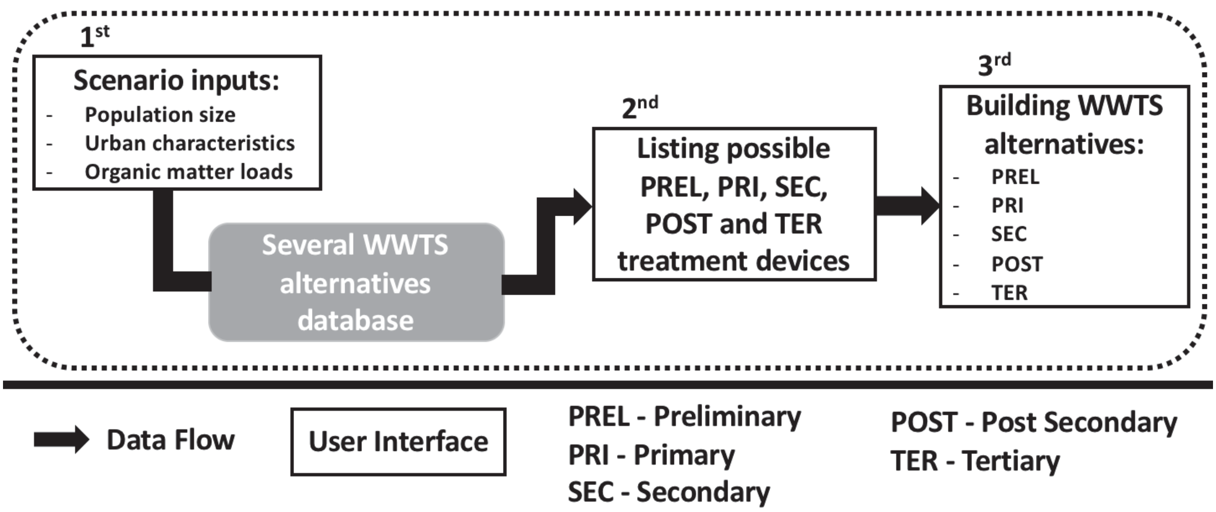
Turning now to the interaction approach of the PS-WWTS, the tool is divided into three levels, as depicted below (see Appendix 2 for more details):

- Firstly, the users are inquired to insert three scenario characteristics, namely population size, urban characteristics and organic matter concentration. That information will then guide the rest of the application.
- Secondly, and considering the previously inputted variables, the user is able to access all database of the WWTS alternatives and main concepts of preliminaries, primaries, and finally the group of secondaries, post-secondaries and tertiaries devices.
- Thirdly, the users are required to build a pre-selected WWTS alternative with devices of each stage of the treatment in sequence as their own will. The possibilities at this level still consider the variables also inputted at the 1st level. The 3rd level also presents descriptions of the chosen devices.

Moreover, the database of the PS-WWTS tool contains 27 possible scenarios given the different input variables. Additionally, there are approximately 25 different devices that compose the whole treatment process. Therefore, the users are able to propose more than 200 combinations amidst the primaries, secondaries, post secondaries and tertiary treatment alternatives.

In this view, the PS-WWTS tool's scope is shown in Figure 23, while Appendix 2 presents the meaning of each variable of each step of the application, wherein picture screens of each stage are also shown.

FIGURE 23 – PS-WWTS TOOL SCOPE



SOURCE: The author (2018).

Summing up, in the PS-WWTS application the user is firstly required to provide basic characteristics of the scenario. Subsequently, it indicates all the WWTS possibilities regarding those given variables, and hence already eliminates WWTS alternatives that are not suitable for that scenario. Finally, it allows the user to design WWTS alternatives given their own preferences.

ii) PS-WWTS application

The application of the PS-WWTS tool was performed only with the specialists group. Table 16 brings details regarding the quality and formation of the inquired participants.

TABLE 16 – INDICATORS DEFINITION AND CRITERIA INFO

Participant	Bachelor's Degree	Master's Degree	Doctor's Degree	Experience
1	Civil engineering	Engineering	Civil Engineering	Teaching content related to SS engineering
2	Environmental engineering	Environmental Engineering	Environmental Technology	Teaching content related to water treatment systems
3	Civil engineering	Environmental Engineering		Working at a company in sectors of water/wastewater treatment systems
4	Civil engineering	--	--	Working at a company in sectors of Water management
5	Civil engineering	Civil construction	--	Studying sanitation engineering

SOURCES: The author (2018).

As observed in Table 16, all of the participants have at least a bachelor in engineering (e.g., civil or environmental). In addition, they have a sanitation academic background, some of them teaching undergraduate or graduate students, others are employees of the company responsible for providing SS systems and water management in the region. Additionally, a student developing his PhD in sanitation approaches.

Moreover, in order to test the application and hence the features of the cited tool, a process of pre-selecting a limited number of alternatives for the defined scenario was simulated.

In this view, given the background information regarding SS systems, and more specifically concerning WWTS, the PS-WWTS was only applied with the specialists group. Additionally, during the investigation, but before the application of the PS-WWTS tool, it was introduced an overview of the scenario as presented in section 4.1. This criterion was considered in order to have reliable outcomes resulting from the tool application regarding the specific scenario.

Thus, in the results and discussion chapter, two sets of results from the PS-WWTS application are presented and analysed. First, the set of the most chosen variables characteristics (e.g. population size, urban characteristics and organic matter loads). Second, the set of the three most built WWTS alternatives designs.

iii) WWTS alternatives pre-definition

In order to have an adequate number of alternatives to proceed the evaluation process step of the DMA process, this research has defined the number of four alternatives.

Thus, to validate the pre-definition of the WWTS alternatives, after the application of the mentioned tool, the method has followed two main principles. Firstly, it was analysed the results of the most preferred set of WWTS through the application of the PS-WWTS with the specialists group. Secondly, this research has compared the previous results with the most used set of treatment systems in Brazil. The results and discussion chapter also bring up the outcomes and analysis regarding this step.

4th – PERFORMANCES ESTIMATION

i) Performances' data collection of the pre-defined WWTS alternatives

Regarding each indicator of the set of the pre-defined WWTS alternatives, as depicted in the 3rd step, the analysis of the performances was achieved by assessing data from literature reviewing. Considering that there are available and sufficient data from abundant and reliable number of peer-reviewed papers, the information was organized and presented in a summarized table exposed in the results and discussion chapter.

Finally, the informed data could be further inserted within the ValueCharts tool in order to perform the evaluation process. In other words, the obtained performances from each selected indicator from its respective pre-selected WWTS alternatives were introduced within the ValueCharts tool, as depicted in the next step.

5th – PROCESS EVALUATION

Among several available softwares that support the comparison of different alternatives given a defined set of diverse indicators (for detail see subsection 3.3.2), this research has chosen the ValueCharts tool to perform this step of the process.

In summary, ValueCharts basically consists of a user-friendly tool with internal modelling process capable to support general approaches of multi criteria and alternative analysis (for detail see subsection 3.3.3). Thus, the next stages elucidate how the latest version of the ValueCharts tool was developed, and how the evaluation procedure for this research was accomplished.

i) ValueCharts tool development

The current version of the ValueCharts tool was developed by a group of researches (both graduate and undergraduate students) of the Faculty of Science of the Department of Computer Science (DCS) at the University of British Columbia (UBC), in Vancouver, BC (Canada).

Moreover, this research has gone beyond of just applying the cited evaluation tool proposed by the DCS. In parallel to the construction of the current version of the tool, several simulation tests between different experiments concerning casual approaches were applied, including the subject discussed in this research by this author. The main goal was therefore to enhance the usability of the ValueCharts by non-expert users who usually do not acknowledge background, for instance with regards to this research's subject.

In this view, each previous simulation has pursued the enhancement of the tool itself (in terms of technical, layout and usability performances aspects) as well as the revision of the DMA as approached in this study. These improvement processes were performed during the year of 2016 and beginning of 2017.

Now turning to the creation of the evaluation and the application of the tool, the first requirement for the manager of the evaluation analysis is to create a login account. Afterwards, the manager is allowed “to create a ValueCharts”. At this stage, it is necessary to provide the name of the evaluation, chart description, and password (Appendix 3-A). That information is obligatory to be further accessed by aleatory participants of the created evaluation analysis process (VALUECHARTS, 2017).

The subsequent stage for the manager yet within the evaluation analysis creation is related to inserting a defined set of indicators, and its respective criteria types (Appendix 3-B).

Subsequently, the creation site requires the manager to include a selected set of alternatives and its respective performances given the designated indicators (Appendix 3-C). This was the last stage and then the creation of the evaluation process is concluded. The tool is now available to be applied by different users.

Turning now to the users’ interface, the first stage for the application with participants also contemplates the creation of a login account. Although the first difference is that an account is not mandatory since the user is allowed to participate by continuing as a “temporary user”, only by giving names. The second stage is to access the created evaluation process by providing the “ValueCharts Name” and a respective “Password”.

The following two stages of the application process for users can be summarized as to ‘define score functions’ (Appendix 3-D). Thus, after accessing a created evaluation process, the users are demanded to input their preferences regarding each indicator previously defined in the creation stage by the manager.

The last step of the evaluation is named ‘set priorities’ (Appendix 3-E). In other words, the users are then required to click on their preferences regarding the whole spectrum of the available set of indicators, in which the user’s weights are defined by the order of clicking.

Summing up, the tool works in such a way for the users: they are firstly required to insert preferences of each indicator given the respective evaluation criteria, and afterwards inquired to provide preferences in terms of the importance of the indicators by comparing them and clicking from the most to the least important.

Finally, after clicking on the ‘View Chart’ button, the ValueCharts tool provides the results for each user who perform the evaluation process. The Appendix 3-F represents an example of the result chart after the application of the tool, wherein two fictitious users have inputted their preferences in a simulated evaluation process.

ii) ValueCharts tool application

A pertinent discussion related to the definition of the most suitable WWTS alternatives have encompassed the importance of isolating participants in groups and accessing the respective results. For example, by separating the community preferences, and hence to examine the propensities provided by them within the decision analysis. It was relevant to develop this feature during the tool’s construction since it has allowed the access to database inputs from different groups exclusively.

However, a unified analysis considering all preferences, also from all users, was performed as well. It was also important since it has highlighted the diversity of concerns in terms of agreements and controversies of the preferences within those different groups of participants.

In this view, the strategy for data collection was firstly to assemble preferences from specialists, afterwards from community, and finally from government authorities, as depicted ahead:

- In light of this approach, first the plan has started with the specialist group users who were required to apply the ValueCharts tool, and then to fill in a questionnaire (Appendix 2).
- Second, a semi-structured interview (Appendix 3) with the community group was applied. The interview has become necessary given the extensive number of technical terms that could not be so familiar considering the lack of technical background of this group. In other words, in this case the reliability of the data collection is based on the capacity of the applicator, who had to translate strictly technical information into understandable and palpable knowledge. It is important to highlight that interviewing the community was preferred since the data collection occurs during in-depth conversations between the interviewer and the respondent.

- Lastly, the data from the government group were collected from direct application of the ValueCharts tool, followed by the application of questionnaire.

To control for bias, measurements were carried in the application of the ValueCharts tool with the government and community groups. In order to collect reliable and usable preferences from non-specialists in the SS field, technical terms such as BOD and nutrients removal were explained as simple and understandable consequences in the ecosystems. The same approach was used in the semi-structured interview with the community group.

In addition, both semi-structured interviews and questionnaires were designed for evaluating investigations using the Likert scale for the evaluation and preferences questions. As stated by Joshi *et al*. (2015), the Likert scale can be either symmetric or asymmetric, which depends on the options' number. The two extremes marks are conventionally 'strongly disagree' and 'strongly agree', wherein the participants are able to provide their preferences.

In order to analyse the outcomes, this research has firstly considered data obtained from application of the evaluation process considering all participants as a single result, and separated results from each group.

Thus, the behavior of the integral result was firstly evaluated. It was achieved by applying the tool with all participants without any differentiation of the representativeness within the chosen scenario. From applying the ValueCharts tool, the first result of the most suitable alternative with regards to all participants was known. Assessing the result charts, besides the visualization of the final outcomes related to the WWTS, the manager can also investigate the average weights given by the participants, or even better, to which indicator the general preferences are been mostly addressed.

Besides, the behaviors of the individual groups were also assessed. For instance, observing the preferences of the community, government, or specialists separately. In this case, thus, in order to obtain the most suitable WWTS alternative for each group, the results from the averages of the participant group's preferences were evaluated. After concluding this stage, the manager is able to perform again the evaluation of the averages of those three groups, where a new result will be obtained from a new group of three participants (e.g. households, technical experts, and governors).

Evidently, it could be inferred that the results in this second case can be deliberated as biased, considering for example that the representative in terms of number of available persons in the group of people from community is greater than the others. In this view, the number of participants in the set of the included groups were further normalized equally as one participant.

By considering the results, it might be relevant since it can show the preferences of each group, and thus the outcomes can reveal which indicator, or even criteria, each group of participants are more concerned.

The next item provides the necessary information of how the analysis of this step of the research was performed, given the results obtained from the application of the ValueCharts tool.

iii) Obtention of a WWTS alternative

By applying the ValueCharts tool with the participants and modeling the preferences, the tool has provided the hierarchization of the pre-defined WWTS alternatives.

Finally, and not less important, it is also possible to inspect the weights given by the participants. This information is relevant since it shows the trend of classes of indicators (e.g. environmental, social and economic). Additionally, it allows to perceive the predilection of each group of participants in order to analyse more profoundly the most suitable WWTS alternative.

6th – RESULTS ANALYSIS

i) WWTS outcomes assessment

By inserting the pre-defined WWTS alternatives within the ValueCharts and applying the tool with the participants, the gathered preferences were hence modeled within the tool. Afterwards, it has provided the scores of the cited WWTS alternatives, wherein it was therefore possible to obtain the 'winning' WWTS alternative.

In order to discuss the related outcomes, the following questions were elaborated:

- Which is the preferred ValueCharts' WWTS alternatives by each group of participants?
- Which is the preferred WWTS alternatives within the application of the ValueCharts tool by all participants?

Finally, from the population sample, it was performed a statistical analysis based on 95% confidence and in the equation 3 in order to evaluate the highest scoring WWTS alternatives.

$$n = \frac{N.\sigma^2.(Z\alpha/_2)^2}{(N-1).E^2+\sigma^2.(Z\alpha/_2)^2} \qquad \text{Equation 3}$$

Where according to Levin (1987), n is the sample size and N is the size of the total individuals' sample, $Z\alpha/_2$ is the critical value correspondent to the confidence level, α is the standard deviation and *E* is the admited error.

ii) System proposal

Based on the obtained results from the previous stage, and considering the main objectives of this study, this stage has aimed to propose a first draft of a suitable WWTS alternative that could be further implemented in the selected scenario. It also targets to provide to the community a feasible research result.

iii) SDM and tools assessment

The final stage of the study comprises both quantitative and qualitative evaluations. Therefore, the data assessments were performed by the analysis of the outcomes of the application of the tools and also of the questionnaires.

Additionally, during the direct application of the tool, possible syntax errors, malfunctions and suggestions for the tools, and also for the whole decision making process, were vigorously examined, especially those suggestions considered relevant by the participants. They were hence incorporated into the proposition of improving the SDM in order to achieve one of the outlined specific objectives.

In this view, the discussion chapter has sought to answer the following questions:

- What are the most weighted and cited indicators between those pre-defined ones to the ValueCharts tool?
- Has it been identified any bias related to the chosen indicators by applying the ValueCharts tool?
- Has it been identified any trends of responses given the formation and positions of the ValueCharts' participants?
- Were the users willing to use the PS-WWTS and ValueCharts tools in future works related to pre-selecting WWTS alternatives?
- Were the PS-WWTS and ValueCharts tools considered: i) user-friendly, and ii) easy to visualize and interact?
- Have the users suggested modifications to the PS-WWTS and ValueCharts tools?
- Were there other listed decision making systems or tools provided by the participants?
- Was the whole process considered feasible to result in a suitable alternative?
- Have all groups of participants felt their opinion relevant to participate in the decision making process?

Based on the obtained results of the SDM and tools opinions, information were gathered and then improvements were proposed. Indeed, this activity is a fundamental procedure related to the SDM process.

In this view, even though the SDM as proposed by Gregory et al. (2012) is represented by a cyclic design, the last stage of the decision analysis should not conclude the DMA process. Actually, it means that the process should be rebounded considering those responses and improvements. In spite of that, this research was not able to perform a new round of the DMA process considering the available time, and the expected objectives.

5 RESULTS AND DISCUSSION

This chapter presents and discusses the results by applying the depicted method. It follows the sequence as defined in the framework of the defined SDM instrument (see Section 4.2), which basically aims to present the outcomes and considerations of each step of the Structured Decision Making (SDM). Therefore, by applying the SDM, tools, interviews, and questionnaires, the behaviors and perspectives of the groups of participants were achieved and demonstrated in this chapter.

Summing up, the next sections present the results and discussion from the application of the adapted decision making analysis (DMA) of the applied study defined for this research, wherein it debates results from the second to the sixth steps, since the first one was discussed in the previous chapter.

1st – SCENARIO DESCRIPTION

a) Applied study site characteristics

The Jardim Arapongas and Esplanda community have approximately 247,000 m^2, in which resides approximately 2,000 people, being the amount of about 650 houses and considering 3 people per household. Since official data regarding HDI was not found for those cited communities, based on observation there were not any types of WWTS, or simple sewerage coverage available for the households. Additionally, many evidences of poverty (e.g., not asfalted public roads, raw sewage disposed in gutters, etc.) were found during the interviews.

2nd – INDICATORS DEFINITION

a) Database outcomes

Table 17 describes the outcomes related to the frequency of occurrence, in which it has allowed this investigation to evaluate the variety and replication of indicators commonly used concerning the main subject.

TABLE 17 – FREQUENCY OF OCCURRENCE OF WIDELY USED INDICATORS WITHIN 22 PAPERS RELATED TO THE WWTS FIELD

Environmental Indicators	%
Nitrogen removal – NH3-N	68%
Phosphorus removal – TP	68%
Organic matter removal – BOD	59%
Organic matter removal – COD	41%
Land Requirements	36%
Consumption of Electricity	32%
Pathogens removal – Fecal coliforms	27%
Total suspended solids removal – TSS	23%
Global warming potential	23%
Chemicals consumption	23%
Total solids removal – TS	18%
Availability of material and components of the WWTS	9%
Resources recovery	9%
Production of sludge	9%
Acidification	9%
Environmental benefits	9%
Availability of power source	5%
Availability of land	5%
Topography	5%
Average of temperatures	5%
Amount of Rainfall	5%
Biogas recovery	5%
Promotion of sustainable behavior	5%
Recovery of phosphate	5%
Abiotic depletion	5%
Residuals management	5%
Water reuse	5%
Heavy metals removal	5%
pH	5%
Conductivity	5%
Alkalinity	5%
Hardness	5%
Groundwater preservation	5%

Economic Indicators	%
Operational and Maintenance (O&M) costs	73%
Capital costs	68%
User costs	9%
Land costs	5%
Availability of funds	5%

Social Indicators	%
Acceptance	23%
Staffing requirements to operate the WWTS	18%
Odor	14%
Community size served	14%
Local waterborne diseases (hepatitis, cholera, etc.)	14%
Participation	14%
Availability of professional skills	9%
Population density	9%
Endemic vector-borne diseases (yellow fever, malaria, etc.)	5%
Population growth	5%

Technical Indicators	%
Flow	23%
Robustness	18%
Reliability	14%
Flexibility	9%
Operation simplicity	9%
Difficulties to expand	9%
Use-ability	5%
Replicability	5%
Failure probability	5%
Technology efficiency	5%
Innovation degree	5%

SOURCE: Ellis and Tang (1991); Hellström *et al.* (2000); Loetscher and Keller (2002); Kiker *et al.* (2005); Engin and Demir (2006); Biswas *et al.* (2007); Gallego *et al.* (2008); Muga and Mihelcic (2008); Massoud *et al.* (2009); Nogueira *et al.* (2009); Foley *et al.* (2010); Katukiza *et al.* (2010); Hernández-Sancho *et al.* (2010); Molinos-Senante *et al.* (2010); Rodriguez-Garcia *et al.* (2011); Kalbar *et al.* (2012); Juznic-Zonta *et al.* (2012); Tanner *et al.* (2012); Balkema *et al.* (2012); Venkatesh *et al.* (2014); Garrido-Baserba *et al.* (2016); Lienert *et al.* (2016)

Thus, this stage commences by performing an examination within the academic literature, notably with respect to the widely used indicators in the field of using DMA within the environment evaluations content. In this view, by performing the database assisted analysis from the use of the ASCE mechanism, it was collected data from 22 scientific papers which have encompassed content concerning the definition of suitable WWTS alternatives into different scenarios. As seen in Table 17, the studies have considered mostly environmental, social, economic aspects in its comparison methods.

By analysing the reported studies of Table 17, it can be pointed out that there is an apparent tendency related to the definition of the indicators. On the one hand, a minority set of indicators (e.g. ‘nutrients removal’, in both terms of N and P, as well as ‘O&M costs’ and ‘capital costs’) represents ranges of repetition over 60%. On the other hand, the majority of the indicators shown in the same table does not appear in more than 9% of the total studies explored.

When defining an adequate group of indicators for implementing within the SDM, part of the indicators has to be excluded. The four principles for the definition were: (i) representativeness, specifically in terms of the percentages of repetition from a delineated boundary for this research (15% of repetition of the 22 researches), and hence those above that line were considered non-relevant; (ii) overlaps and similarities detection; (iii) the indicators should contemplate the three main groups (environmental, economic and social); (iv) the availability of performance data.

The next subsection details the final defined group. There was only one exception, and it was related to the social group, as further elucidated.

b) Final set of indicators and performances criteria

As further observed, the number of indicators was reduced from the original 47 (Table 17) to only 11, and they were divided into three main groups of indicators (e.g. environmental, economic and social).

The following discussion is separated into those mentioned groups of indicators. In addition, this subsection also presents the criteria types and measurement of each indicator.

Therefore, by applying the four principles previously depicted, the list of defined indicators for this study has ended as depicted in Table 18.

TABLE 18 – DEFINITION OF THE INDICATORS

Group	Indicators	Representativeness
Environmental	BOD removal	59%
	NH_3-N removal	68%
	TP removal	68%
	TSS removal	23%
	FC removal	27%
	Land requirements	36%
	Consumption of electricity	32%
Economic	Capital costs	68%
	O&M costs	73%
Social	Odor potential	14%
	Staffing requirements	18%

SOURCES: The author (2017).

From the analysis of the left subtable regarding the environmental group of indicators (Table 17), the first two rows are related to organic matter concerns – i.e., Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Given that the aim of this stage was to define an optimum number of indicators by eliminating overlaps when possible, and despite the fact that both BOD and COD are well-known reliable parameters, this study has only considered the BOD parameter. The reason for that establishment lies on the fact that BOD has presented more representativeness in comparison to COD within the researches' database (59% and 41%, respectively).

Additionally, the chosen parameter associated to solid removals was the Total Suspended Solids (TSS), given its relevancy in comparison to the TS (Total Solids). Respectivelly, within the analysed papers sources, the TSS has presented a higher repetition of 23% in comparison to 18% related to TS (see Table 17). Conclusively, the criteria for elimination of overlaps was repeatedly used regarding the solids removal subject.

Focusing now on the nutrients aspects, although both Nitrogen (N) and Phosphorus (P) may be related to the eutrophication issue, both were included within the set of indicators of the SDM process. In this view, N and P might indicate different sources of wastewater (e.g., toilet and kitchen, respectively), and the treatment may consider distinct processes.

The last parameter related to the characteristics of the wastewater is the Fecal Coliforms (FC). It indicates the probability of the presence of infectious bacteria content within the wastewater, and for that, it was also considered a relevant parameter.

Additionally, the analysis of Table 17 presents the FC removal indicator with 27% of repetition; hence, the indicator was admitted within the set.

The evaluation criteria concept for those main characteristics of the wastewater are briefly described in Table 19. The variables and variations of each indicator are also specified.

TABLE 19 – VARIABLES OF THE CRITERIA TYPES RELATED TO ENVIRONMENTAL INDICATORS

Indicators	Efficiency's ranges for the categories (%)		
	I – Unsatisfactory	II – Acceptable	III – High
BOD removal[1]	[0, 75[	[75, 88[	[88, 100]
NH_3-N removal [1]	[0, 75[	[75, 88[	[88, 100]
TP removal [1]	[0, 70[	[70, 80[	[80, 100]
TSS removal [1]	[0, 70[	[70, 93[	[93, 100]
FC removal [2]	[0, 90[	[90, 99[	[99, 100]

SOURCES: [1]Silva *et al.* (2014); [2]Adapted from von Sperling (2005).

Those indicators outlined in Table 19 were characterized as 'categories' (a criteria type term used within the ValueCharts tool) in order to facilitate for users when applying the tool as part of the decision making process. The categories were divided into three classifications (e.g. Unsatisfactory, Acceptable, High) that correspond to the ranges of the WWTS alternatives efficiencies. Silva et al. (2014) have highlighted in their study a similar classification to the one defined in this method.

The 'consumption of electricity' and 'land requirements' indicators were also selected considering their representativeness over 15% within the set of researches examined. Still, both indicators were considered as 'continuous' (another different criteria term) which indicates that they are strictly dependent on values such as square meter and kWh by treated volumes, respectively.

Finally, both excluded indicators with ranges of recurrence above 15% within the environmental group were the global warming potential (GMP) and chemicals consumption. Those are examples of a relevant indicator that information of performances with regards to the 'greenhouse gas emissions' and chemicals requirements could not be obtained during the development of this research. In fact, data of this parameter for conventional systems could be achieved, except for the EETS in which there were no data for both indicators in literature review.

Turning now to indicators related to economic aspects, the Capital Costs and Operation & Maintenance (O&M) Costs indicators follow the same principle as outlined for indicators connected to environmental approaches, the principles associated to their relevancies and with regards to the availability of information to perform further comparisons.

It is important to emphasize that 'capital costs' usually incorporate those investments associated to the construction of all necessary elements for running a WWTS. For instance, administrative offices and other basic and necessary facilities usually found at the WWTS sites. In addition, the costs of the lands' acquisition were not considered. The reason is that this type of costs might be excessively different for each scenario, in the view of data collection from the literature review. Besides, the analysed researches used as sources in this study have not clearly considered costs of the lands. Despite the fact that the costs related to the implementation of preliminary devices (e.g. Screen, Grit chamber, Grease Trap) in the examined studies were not clear, they were assumed as a component within the implementation costs.

Turning now to the O&M costs, and following the same criteria as depicted for capital costs, those connected to manpower, power, repair, and use of chemicals were included in order to achieve a specific average, similarly to what was depicted by Sato *et al*. (2007).

Concluding, in relation to the economic group, both indicators were considered as 'continuous' evaluation criteria within the ValueCharts. Hence, the outcomes for them are absolute values, namely total costs in US dollars ($) divided by the volume (m^3) treated daily.

Finally, approaching the social aspects, the definition in respect to 'staffing requirements' has also followed the principle of considering their relevancy, similarly to the previous indicators.

Going through this principle, both 'acceptability' and 'staffing requirements' indicators should be selected. In spite of the fact that there are reliable studies and sufficient information with respect to 'acceptability' for conventional systems, it was eliminated given the fact that the Ecologically Engineered Treatment System (EETS) is considered relatively new, not broadly implemented yet, and hence there were no sufficient data for proceeding reliable comparisons.

On the other hand, given that the data of the 'staffing requirements' indicator concerning widely used WWTS could be easily estimated from literature review, the performances for the same indicator related to the EETS were measured analysing a similar WWTS process (i.e. the ASP).

Moreover, the evaluation criteria for ‘staffing requirements’ was also described as ‘continuous’, in which the measurement unity is the number of staff divided by the treated volume of wastewater, similarly to Muga and Mihelcic (2008).

In this view, for establishing the performance of this indicator for all WWTS alternatives, it was assumed a fictitious wastewater flow of approximately 200,000 people discharging an average of 100 liters of sewage per person per day, as estimated by the Brazilian’s regulation (BRAZIL, 1997).

Indeed, as previously stated in Subsection 3.2.2, the centralized WWTS approaches associate flows of sewage which exceed 10,000 people. Thus, the ficticius volume of the mentioned wastewater daily generated might also represent an adequate flow, since it is encompassed within an average range of sewage treatment capabilities of the selected conventional WWTS for the evalution process of this research.

Finally, regarding social aspects, in order to have a minimum balance between the numbers of indicators for each group in function of their representativeness, this research has selected one more indicator related to this cited group. This specific indicator was the only one that had representativeness below 15%. In this view, for this specific case, the analysis overcame the previously stablished and hence had minimum relevancy limit of 15% for those 22 data papers.

Additionaly, considering data availability and also that this study intends to inquiry people from the chosen community, according to Muga and Mihelcic (2008) the ‘odor potential’ indicator was selected since it can be both easily evaluated and also be relevant within inquiries with people who would be supposedly affected by the selected WWTS. The evaluation criteria for odor potential follows the ‘category’ approaches, as depicted in Table 20.

TABLE 20 – CATEGORIES AND CONSEQUENCES OF THE CRITERIA FOR ODOR

Categories	Definition	Consequences
I	High odor potential	It produces strong stench and often brings discomfort to neighborhoods and specially to operators
II	Medium odor potential	It causes discomfort within the WWTS site, hence to operators, and in rare cases to neighborhoods.
III	Low odor potential	It is only weakly perceptible within the WWTS site.

SOURCE: Adapted from Muga and Mihelcic (2008)

Additionally, in order to define the performances and the odor potential related to the treatment systems selected for this research, it was used the same reference as considered in Muga and Mihelcic (2008), who have also adapted from the WEF (1992). In this view, Table 21 indicates the odor potential for several criteria of different treatment process.

TABLE 21 – ODOR POTENTIAL FOR DIFFERENT TREATMENT PROCESS

Unit processes	Odor potential
Treatment plant	
Preliminaries	High
Primary clarifiers	High
Trickling Filters	High
Aeration	Low
Lagoons	Moderate
Terrestrial	Low/Moderate
Anaerobic	High
Secondary clarifiers	Low/Moderate
Sludge Handling	
Thickening/Holding	High

SOURCE: Adapted from Muga and Mihelcic (2008) and WEF (1992)

As seen, Muga and Mihelcic (2008) have provided a worthwhile definition of the odor approach. It is basically based on the process of the treatment analysed. In other words, it consists in an investigation on whether the selected WWTS alternative contemplate aeration devices or anaerobic technologies. Therefore, considering the intrinsic technologies of each WWTS selected, the degrees of odor potential can be established.

Finally, Table 22 illustrates the breakdown of the criteria types and measures correlated to the selected indicators.

TABLE 22 – INDICATORS DEFINITION AND CRITERIA INFO

Groups	Indicators	Criteria type	Criteria info/ measures
Environmental	BOD removal	Categories	I, II and III[1]
	NH_3-N removal	Categories	I, II and III[1]
	TP removal	Categories	I, II and III[1]
	TSS removal	Categories	I, II and III[1]
	FC removal	Categories	I, II and III[1]
	Land requirements	Continuous	m^2 / m^3 / d
	Consumption of electricity	Continuous	kWh / m^3 / d
Economic	Capital costs	Continuous	$ / m^3 / d
	O&M costs	Continuous	$ / m^3 / d
Social	Odor potential	Categories	I, II and III[2]
	Staffing requirements	Continuous	p. / m^3 / d

NOTES: [1] 'I' – Unsatisfactory, 'II' – Acceptable, and 'III' – High.
[2] 'I' – High, 'II' – Moderate, and 'III' – Low.
SOURCES: 'Criteria info/measures' adapted from von Sperling (1996), von Sperling (2005), Muga and Mihelcic (2008) and Silva *et al*. (2014).

3rd – PRE-ALTERNATIVES EXAMINATION

This section corresponds to the third step of the adapted SDM method, and hence to the pre-alternatives examination step. Considering the pre-selection of WWTS (PS-WWTS) development as detailed in the material and methods, this section was divided into two more subsections. First of all, the obtained results from the application of the cited tool were presented. Secondly, the WWTS alternative pre-definition and the comparison with the most used set of treatment systems in similar scenarios are discussed.

a) Obtained results from the PS-WWTS tool application

The first set of obtained results presents the preferences related to the scenario's characteristics, while the second shows the propensities associated with the WWTS.

In this view, all of the participants have chosen the variable 'intermediate' for the size of the population. This size represents a community of 10 to 5,000 people. For example, around two thousand people live in the Jardim Arapongas and Esplanada areas, thus this community is inserted in the intermediate category (see 3rd step of the Section 3.2).

Moreover, each inquired applicant has selected the ‘peri-urban areas’ as a second variable in reference to the basic urbanistic characteristic. Certainly, the Jardim Arapongas and Esplanada community also have the demographic density corresponding to the most selected in the PS-WWTS application. Additionally, there are possibilities of implementing decentralized WWTS at the river downstream near the cited community perimeter.

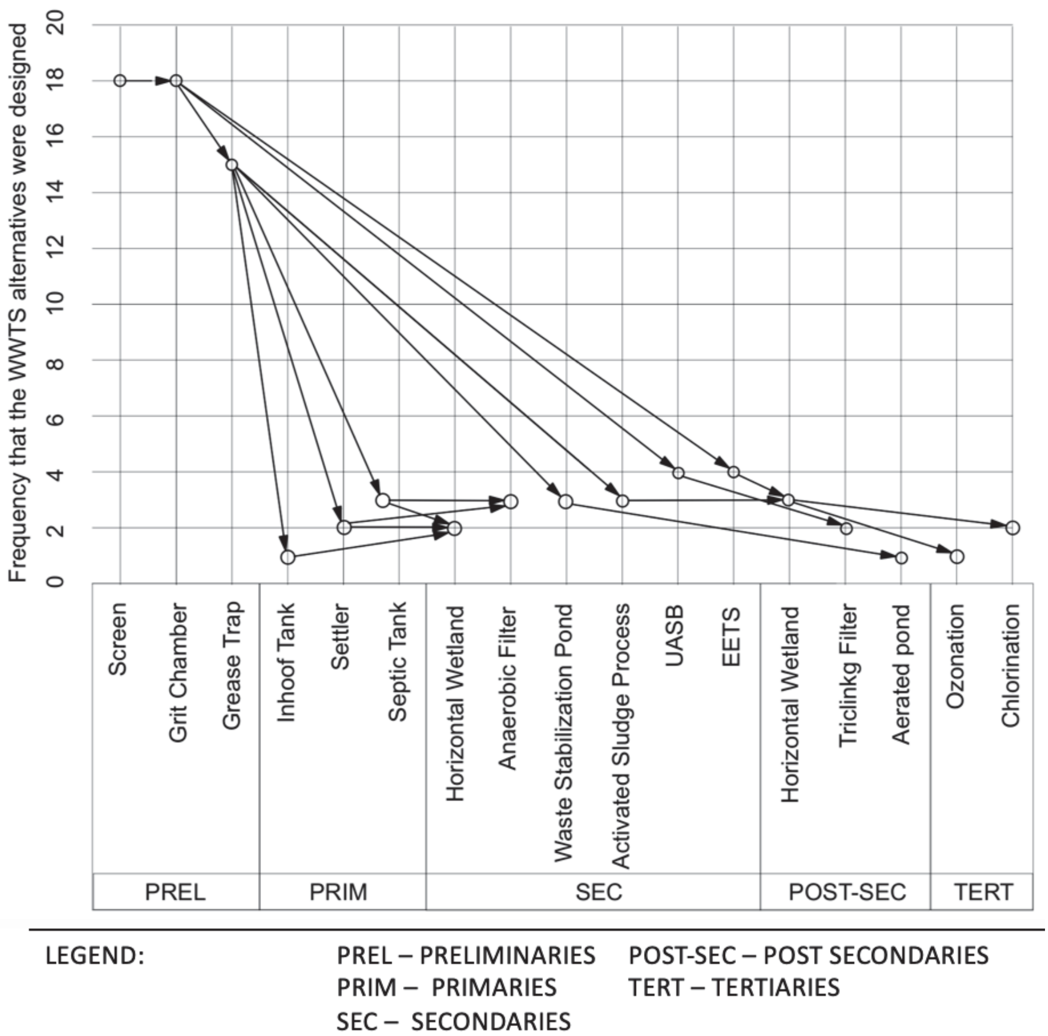
Finally, regarding the organic matter loads, the entire group of participants have also selected medium concentrate of organic matter loads. In other words, the COD concentrations in this category correspond to ranges between 150 mg/L and 600 mg/L, according to the average concentrations of Brazilian’s sewage and therefore the applied scenario.

After the application of the first step of the PS-WWTS tool, coherent results with the real scenario of the applied study can be inferred. In addition, the set of results were uniformed for all participants, and also correspond to the real characteristics of the selected scenario.

Changing now the focus to the subsequent subject of the PW-WWTS application, the second set of obtained results is related to the establishment of WWTS alternatives. This approach has also aimed at the proposal set for the defined scenario. At this point, the group of specialists was required to build from three to four alternatives each. In total, the investigation has collected 18 different pre-defined WWTS alternatives (Figure 24), wherein it is possible to identify the frequency that each different WWTS alternative was designed by the specialist applicants.

In this view, as shown in Figure 24, there is a tendency for designing the same set of preliminaries devices by all participants. Screen and Grit Chamber are the chosen devices in 100% of the suggested system, while the Grease Trap was withdrawn in three WWTS alternatives designs by one of the five applicants.

FIGURE 24 – PRE-DEFINED WWTS ALTERNATIVES FROM THE PS-WWTS TOOL APPLICATION



SOURCE: The author (2018).

Moreover, regarding the primary devices, the Septic Tank was chosen three times, always followed by Anaerobic Filter. Indeed, those devices make sense for the aimed community since this composition might be considered as a decentralized solution. The Settler and the Imhoff Tanks were also selected by the participants. In general, selecting devices from primary stages of treatment separately when building the alternatives has not been presented as relevant in relation to the total built designs. In other words, primary devices were defined only in 39% of the applications.

Turning now to the secondaries, it is relevant that EETS was chosen in 80% of the cases of pre-defined WWTS alternatives, which is present in four designs. Probably, the reason lies on the fact that the PS-WWTS tool displays a summarized explanation of the treatment process. In addition, as previously depicted, the EETS was specifically designed for decentralized approaches (as the scenario selected) in which sustainable characteristics are also contemplated. Those aspects are other current demands in the environmental engineering field.

Moreover, the Upflow Anaerobic Sludge Blanket (UASB) alternative was also designed four times by the participants, while the third and fourth positions have belonged to the Activated Sludge Process (ASP) and Waste Stabilization Pond (WSP) with three designs each.

Even though the Horizontal Wetlands might be considered both secondary and post-secondary treatment systems, it was mostly selected in the case of post-secondary designs. The reason is probably the operational and maintenance difficulties and the required surface areas for implementation within secondaries treatment approaches.

Regarding the tertiary, or advanced, devices, what stands out in Figure 24 is that those were selected in few cases, wherein the chlorination was the mostly defined device, followed by the ozonation (11% and 6% of the participants' built designs, respectively).

Finally, Table 23 summarizes the four sets of pre-defined WWTS alternatives and their representativeness from the application of the PS-WWTS tool.

TABLE 23 – SUMMARY OF THE MOST DESIGNED WWTS ALTERNATIVES FROM THE PS-WWTS APPLICATION AND THEIR RELEVANCIES

<table>
<tr><th>Preliminaries</th><th>Primaries</th><th>Secondaries</th><th>Post-secondaries</th><th>Tertiaries</th></tr>
<tr><td rowspan="4">Screen-100%
Grit chamber-100%
Grease trap-83%</td><td colspan="2">EETS-22%</td><td></td><td>--</td></tr>
<tr><td colspan="2">UASB-22%</td><td>Trickling Filter-17%</td><td>Chlorination-11%</td></tr>
<tr><td colspan="2">Waste Stabilization Pond-17%</td><td>Aerated Pond-17%</td><td>Ozonation-6%</td></tr>
<tr><td colspan="2">Activated Sludge Process-17%</td><td>Wetland-6%</td><td>--</td></tr>
</table>

SOURCE: The author (2018).

b) WWTS pre-alternatives definition

The pre-definition of the WWTS alternatives that were used within the final evaluation decision was achieved not only by using the PS-WWTS, but also by comparing those PS-WWTS tool outcomes with the most used within the Latin American Countries, as depicted in Section 3.2.

In this view, as previously reported in Figure 5-A and 5-B (NOYOLA et al., 2014), the group of WWTS alternatives that represent approximately 85% of the total chosen technologies for Brazil are WSP, UASB, and ASP. It is important to highlight that in a research by Noyola et al. (2014), in most of the cases those systems were designed for centralized scenarios – i.e., great cities with more than 10,000 people.

Additionally, the comparison of the pre-defined WWTS alternatives obtained from the application of the PS-WWTS with the data of the conventional systems usually built in Brazil (Figure 6), the same pattern could be noticed. That is, the participants have followed the commonly implemented alternatives, in particular in terms of the wastewater treatment devices until the secondary stages.

Nevertheless, the few differences that can be noted are related to the option of installing tertiary devices when there are not Constructed Wetlands as post-secondaries treatments (in the cases of the WSP and ASP, for instance).

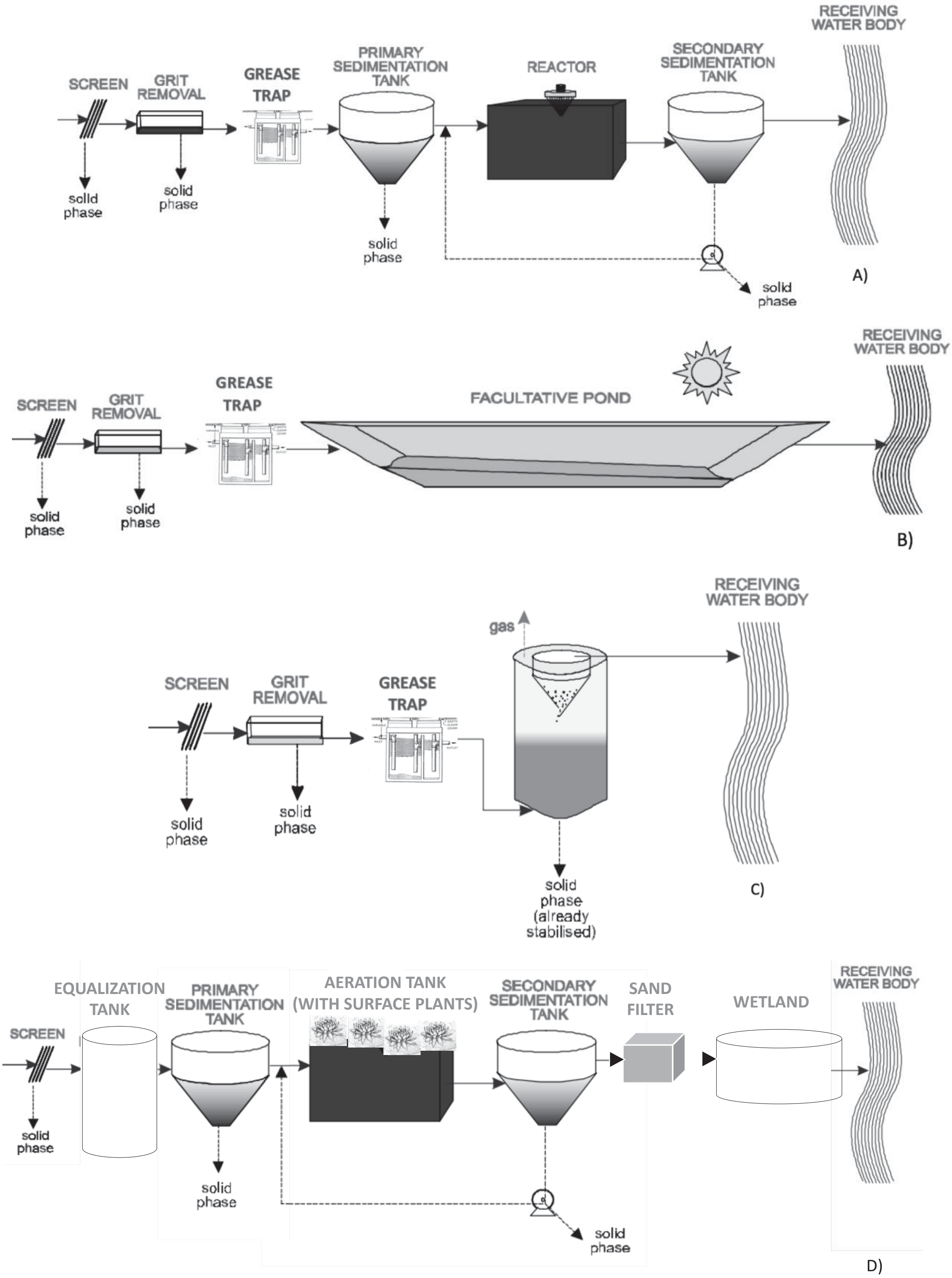
Thus, the set of the pre-defined alternatives basically follows those chosen in Table 23. However, there are exceptions in some aspects within the technical design between the intrinsic aspect of each selected alternative and those that were further used within the 5th step of the SDM. The few differences are especially concerning some stages of the treatment process (i.e. preliminaries, post secondaries and tertiaries).

In this view, this research has assumed that the conventional WWTS alternatives inherently contemplate preliminaries devices. Nevertheless, in the case of the EETS, the wastewater is loaded directly into the system by a pump, which partially performs filtration of the wastewater given a screen located within the pumping equipment. In other words, the preliminaries stage and objectives are also performed similarly, but through the use of different devices.

Regarding the WSP, it was considered a system composed of a facultative pond, given the collected data set regarding its performances. Additionally, in the case of UASB, it was assumed without post secondaries technologies, in spite of the fact that it is notorious that UASB requires additional treatment. Finally, the third WWTS alternative, within the set of conventional ones, is the ASP, also defined without post-secondary or tertiary treatment devices.

Figure 25 presents the main flowsheets of the pre-defined conventional WWTS alternatives further used in the evaluation step of the adapted SDM process.

FIGURE 25 – FLOWSHEET OF THE CONVENTIONAL PRE-SELECTED WWTS: A) ACTIVATED SLUDGE PROCESS; B) WASTE STABILIZATION POND; C) UPFLOW ANAEROBIC SLUDGE BLANKET; D) ECOLOGICALLY ENGINEERED TREATMENT SYSTEM



SOURCE: Adapted from von Sperling and Chernicharo (2005) and Ecotek (2016).

Table 24 summarizes the main characteristics of each pre-defined WWTS alternative.

TABLE 24 – SUMMARY OF THE PRE-DEFINED WWTS ALTERNATIVES FROM THE PS-WWTS TOOL APPLICATION AND THEIR CHARACTERISTICS

Treatment System	Characteristics
Activated Sludge Process (ASP)	An ASP refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics to produce a high-quality effluent in terms of organic matter dischargings. However, the defined typology of ASP has not contemplated advanced technologies within the system for nutrients removals. Finally, to maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required.
Waste Stabilization Pond (WSP)	Wastewater flows through a pond constructed for wastewater treatment, wherein remains for many days. The soluble and fine particulate BOD is aerobically stabilised by bacteria which grow dispersed in the liquid medium, while the BOD in suspension tends to settle, being converted anaerobically by bacteria at the bottom of the pond. The required oxygen by the aerobic bacteria is supplied by algae through photosynthesis.
Upflow Anaerobic Sludge Blanket (UASB)	The UASB is a single tank process. Wastewater enters the reactor from the bottom and flows upward. A suspended sludge blanket filters and treats the wastewater as the wastewater flows through it.
Ecologically Engineered Treatment System (EETS)	The EETS use greenhouses to enhance the growth of algae, plants, bacteria and aquatic animals, sewage flows through a series of aerated, plant covered tanks and constructed wetlands. The treatment occurs in many stages and the main sources are sunlight, biodiversity and natural processes in order to create clean water with the by-products of natural gases and biological material.

SOURCE: Teal (1993), von Sperling and Chernicharo (2005) and Tilley et al. (2013).

All data for those three conventional WWTS (i.e., ASP, WSP and UASB) were collected considering centralized approaches. In other words, over a volume of 500 m^3 of domestic wastewater per day, or also a contribution of more than 5,000 people daily. This last factor could cause bias in the evaluation process, since in the selected scenario there are around 2,000 people living in the community. On the other hand, it represents advantages in the decision analysis calculations within the evaluation tool regarding costs, for instance. The reason is that those types of systems, in decentralized situations, tend to be more expensive.

For all of the four pre-defined WWTS alternatives designs (ASP, WSP, UASB and EETS), it was not considered tertiary, or advanced, treatment components given that it was not possible to collect integrated data from all the set of selected indicators used in the ValueCharts tool.

Additionally, another aspect that was not discussed was about the solid-phase subproducts. Despite its importance, especially for aerated systems wherein in this type of systems the sludge generation tends to be larger, as emphasized in the results of the 2nd step (‘b), there were not performances available for the EETS to afterwards performing the comparison.

4th – PERFORMANCES ESTIMATION

This section presents the results and discussion related to the performances of both conventional and the proposed as a sustainable and decentralized WWTS alternative (EETS). The data analysis was collected from the literature review in both cases.

a) Performances of the conventional WWTS alternatives

The performances obtained and gattered from literature review are shown in Table 25. It firstly presents the average performances regarding each previously defined conventional WWTS alternatives. In this view, it considers the means of several different performances of the selected indicators for this applied study. Specifically, researches that have acknowledged the comparison of WWTS by applying DMA.

As seen in Table 25, it basically demonstrates a summary of the evaluation method discussed in Section 4.2. Additionally, this assessment has not separated collected data for efficiencies of WWTS for different population sizes, as well as volumes of treated wastewater. Instead, the purpose of the presented evaluation was to seek for WWTS performances in studies that have evaluated systems’ efficiencies concerning centralized approaches.

TABLE 25 – PERFORMANCES' RANGES FROM THE LITERATURE REVIEW OF THE CONVENTIONAL WWTS

Indicators	Averages Performances (Categories)		
	ASP	**WSP**	**UASB**
Environmental			
BOD removal[1]	88% (III) [A, E, H, J, L, O, Q]	77% (II) [A, H, M]	70% (I) [A, C, H, K]
NH_3-N removal[1]	75% (II) [D]	56% (I) [M]	~0 (I) [N]
TP removal[1]	89% (III) [D]	19% (I) [A, H, M]	23% (I) [H]
TSS removal[1]	77% (II) [D]	60% (I) [H, I, M]	82% (II) [H]
FC removal[1]	90% (II) [A, H]	99.9% (III) [A, H]	72% (I) [A, H]
Land requirements	0.90m^2 / m^3 / d [A, F]	20.08m^2/ m^3 / d [A, F, M]	1.63m^2/ m^3 / d [A, F]
Consumption of electricity	39.5 kWh / m^3 / d [A, L]	~ 0 [A, L]	~ 0 [A, L]
Economic			
Capital costs	$157/ m^3 / d [A, F]	$69/ m^3 / d [F, M]	$137/ m^3 / d [A, C, F]
O&M costs	$0.2/ m^3 / d [J, L]	$0.1/ m^3 / d [L]	$0.18/ m^3 / d ay [L]
Social			
Odor potential[3]	Low (III) [G]	Moderate (II) [G]	High (I) [G]
Staffing requirements[2]	0.0006 p/ m^3 / d [G]	0.0006 p/ m^3 / d [G]	0.0006 p/ m^3 / d [G]

NOTES: [1] 'I' – Unsatisfactory, 'II' – Acceptable, and 'III' – High
[2] Based on a given plant capacity of 3,785 m^3/day
[3] 'I' – High, 'II' – Moderate, and 'III' – Low.
ASP – Activated Sludge Process; WSP – Waste Stabilization Pond; UASB – Upflow Anaerobic Sludge Blanket

SOURCES: [A]von Sperling (1996); [B]von Sperling and Chernicharo (2002); [C]Aiyuk *et al.* (2004); [D]Kraume *et al.* (2005); [E]Colmenarejo *et al.* (2006); [F]Sato *et al*. (2007); [G]Muga and Mihelcic (2008); [H]Oliveira and von Sperling (2008); [I]Tsalkatidou *et al.* (2009); [J]Hernández-Sancho *et al.* (2011); [K]Khan *et al*. (2011); [L]Noyola *et al.* (2012); [M]Mburu *et al.* (2013); [N]Machdar et al. (2014); [O]Rodriguez-Caballero *et al.* (2014); [P]Silva *et al.* (2014); [Q]Romero-Pareja *et al.* (2017)

Additionally, a closer inspection of Table 25 with respect to the data related to ‘Staffing requirements’ (i.e. number of necessary personnel to operate WWTS facilities) denotes that it is necessary one member of staff per 1,666.67 m3 of wastewater daily treated equivalently for those conventional systems. These data were referred from a Muga and Mihelcic (2008) who have presented quantities of required staff to operate and maintain the plant normalized to system capacity.

A similar criterion was used to define the ‘Odor potential’ indicator. The definition of WWTS efficiencies for this indicator was based on types of treatment. In other words, systems that consider, for instance, land, mechanical or lagoon treatment process may have different potential of odor generation. As forward seen, this study has defined that the WWTS which consider mechanical process and aeration devices (e.g. ASP and EETS) have low odor potential. On the other hand, the systems that have contemplate lagoons (e.g. WSP) and anaerobic processes (e.g. UASB), have presented ‘moderate’ and ‘low’ performances, respectively (for details see Table 21).

Another important aspect within the data assessment is the seasonal variations. This concern has been recently discussed in cases of comparison of similar WWTS configurations, which showed different performances of the treatment processes within different scenarios (e.g., high or low temperatures). For instance, the WWTS that operate in high temperatures and warmer environmental climates have shown better performances in terms of organic matter removal, while in colder climates the microbiology degradation processes are not as effective.

Therefore, in spite of the relevancy of both aspects, the seasonal variation indicator was not considered here since the focus was not on the highest scoring alternative given all inherent details of the systems. Rather, the main goal lies in analysing the decision making process itself, and tools, rather than obtaining the most accurate and strict information within the evaluation process.

It can also be seen in Table 25 that the highest efficiencies for organic matter removals correspond to ASP treatment systems. Indeed, most of the efficiency conditions of the ASP are due to the controlled aerobic conditions, which provides adequate environment for the microorganisms to degrade organics. However, since the UASB considers anaerobic process, the conditions for organic matter degradation are not as appropriate as for the aerated ones.

Moreover, the WSP and UASB alternatives have shown approximately zero energy consumption within the process. This aspect clearly brings advantages in the comparison considering developing countries, wherein electric energy costs are usually an important issue for mitigating.

Finally, by analysing the costs' content from Table 25, despite the fact that ASP has shown the higher implementation expenditure in comparison to the other two conventional alternatives (128% and 15% in relation to the WSP and UASB, respectively), the operational and maintenance (O&M) cost has presented similar values.

The next subsection introduces the analysis of the performances obtained from the literature review exclusively for the EETS, while Section 5.5 presents the results and a deeper discussion concerning the application of the comparison tool and also regarding each group of users' preferences.

b) Performances of the proposed EETS alternative

Table 26 shows some data of physical characteristics and costs performances from previous existent EETS obtained from literature. The information was gathered from journals, reports and a company (EcoTek) from EETS' unities recently implemented.

TABLE 26 – PHYSICAL AND COSTS EETS'S PERFORMANCES

Local of Implementation	**Land requirements (m^2)**	**Volume treated (m^3/day)**	**Costs**	
			Capital (US$)	**O&M (US$/year)**
Providence RI - US[A]	334	44	ND	ND
Paws Inc, Albany IN - US[A]	125	6	ND	ND
Errington BC – CANADA[B]	210	38	200,000	14,000
Havana – CUBA[B]	300	150	150,000	5,000
Vancouver – UBC CANADA[B]	85	15	150,000	25,000
Christina Lake BC - CANADA[B]	84	22.5	ND	20,000
Vermount – USA[C]	725	300	ND	ND
Trosa – SWEDEN[D]	180	185	ND	ND
AVERAGES	**247.5**	**89.4**	**166,667**	**16,000**

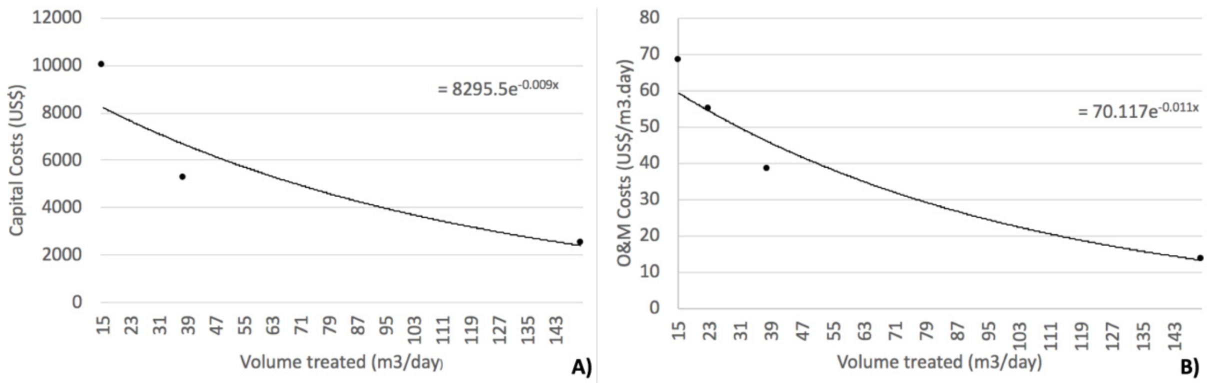
Legend: ND – No Data; O&M – Operation and Maintenance

SOURCE: [A]Wright-Pierce (1993); [B]EcoTek (2016); [C]Todd et al. (2003); [D]Guterstam (1996).

Regarding energy consumption related to the EETS, the only available data was in Trosa (Sweden), wherein according to Guterstam (1996) the amount of used energy for the treatment is 44 kWh/m3/day.

Since all of the analysed EETS, as seen in Table 26, were obtained from systems implemented within small communities, pilot plants and also bench scale, the economic data needs to be normalized. Therefore, instead of using averages, this research has sought for equations to normalize the capital and O&M investiments, considering a higher volume. It intends to convert the budgets in similar conditions of the pre-defined conventional WWTS alternatives, and also to achieve a more realistic comparison. Figure 26 presents the captured curves by assessing the data from Table 26.

FIGURE 26 – GRAPHS FOR DEFINING THE EETS CAPITAL AND O&M COSTS EQUATIONS



SOURCE: The author (2018).

The EETS' values of the 'Capital costs' and 'O&M costs' indicators were obtained through the application of the equations shown within the graphics (Figure 26). The variable 'x' for both cases represents the volume treated. Since the information related to those cited indicators of the conventional alternatives were collected from existing systems in larger scales, this study has considered 2,000 residents to apply the equation. Considering daily 150 Liters per people, it was used 300 m3/day.

Turning now to environmental performances, Table 27 shows removals for each defined indicator for this applied study.

TABLE 27 – ENVIRONMENT EETS'S PERFORMANCES

Local of Implementation	Removal performances				
	BOD	NH_3-N	TP	TSS	FC
Paws Inc, Albany IN - US[A]	ND	98.5%	ND	96.8%	ND
Vermount – USA[B]	96.0%	98.0%	67.0%	98.0%	99.9%
Bench Scale 1[C]	79.1%	ND	ND	ND	ND
Trosa – SWEDEN[D]	90.0%	ND	72.0%	ND	ND
Columbus – USA[E]	ND	78.0%	67.8%	97.3%	ND
Bench Scale 2[F]	87.9%	ND	ND	ND	ND
AVERAGES	**88.2%**	**91.5%**	**68.9%**	**97.4%**	**99.9%**

Legend: ND – No Data

SOURCE: [A]Wright-Pierce (1993); [B]Todd et al. (2003); [C]Mohan et al (2010); [D]Guterstam (1996); [E]Morgan and Martin (2008); [F]Chiranjeevi et al (2013).

As it can be seen in Table 27 and regarding the averages of the environmental parameters, in terms of removal's performances, those previous studies have shown adequate efficiencies. For instance, it is indicated averages of removal rates as 88,2% for organic matter (BOD), 91.5% for ammonia (NH_3-N), 99.9% for bacteria (FC) and 97.4% for solids (TSS), which can be considered highly desirable efficiencies, but at the same time difficult to achieve. The only exception is regarding the unsatisfactory removal rate of the phosphorus (TP) indicator. The referred obtained removal performance is 68.9%.

Therefore, summarizing the obtained EETS performances from Tables 26 and 27, and applying the equations as depicted in Figure 26, Table 28 was elaborated. In order to fill the ValueCharts performances, it follows the same order of the defined indicators in the 2nd step of the SMD.

TABLE 28 – SUMMING UP THE EETS' PERFORMANCES

Indicators	Averages Performances (Categories)
	EETS
Environmental	
BOD removal[1]	88.2% (III)[A]
NH_3-N removal[1]	91.5% (III)[A]
TP removal[1]	68.9% (I)[A]
TSS removal[1]	97.4% (III)[A]
FC removal[1]	91-99.9% (III)[A]
Land requirements[2]	2.8 m^2/m^3.day
Consumption of electricity[3]	44 kWh/m^3.day
Economic	
Capital costs[2]	\$227/m^3.day
O&M costs[2]	\$0.86/m^3.day
Social	
Odor potential[4]	Low (III)[B]
Staffing requirements[4]	0.0006 p./m^3day

NOTES: [A] 'I' – Unsatisfactory, 'II' – Acceptable, and 'III' – High
[B] 'I' – High, 'II' – Moderate, and 'III' – Low
SOURCES: [1]Table 27, [2]Table 26, [3]Guterstam (1996), [4]Muga and Mihelcic (2008).

As seen in the previous table, the only two perfomances that were not directly collected from observation in literature approaching exclusively the EETS are the 'Odor potential' and 'Staffing requirements' indicators. Instead, the same source (MUGA; MIHELCIC, 2008) of the conventional WWTS alternatives was used, considering their intrisic devices within their wastewater treatment processes. Since the EETS have broadly similar treatment processes to the ASP – i.e., both have aerated devices, it was characterized with the same low potential performance.

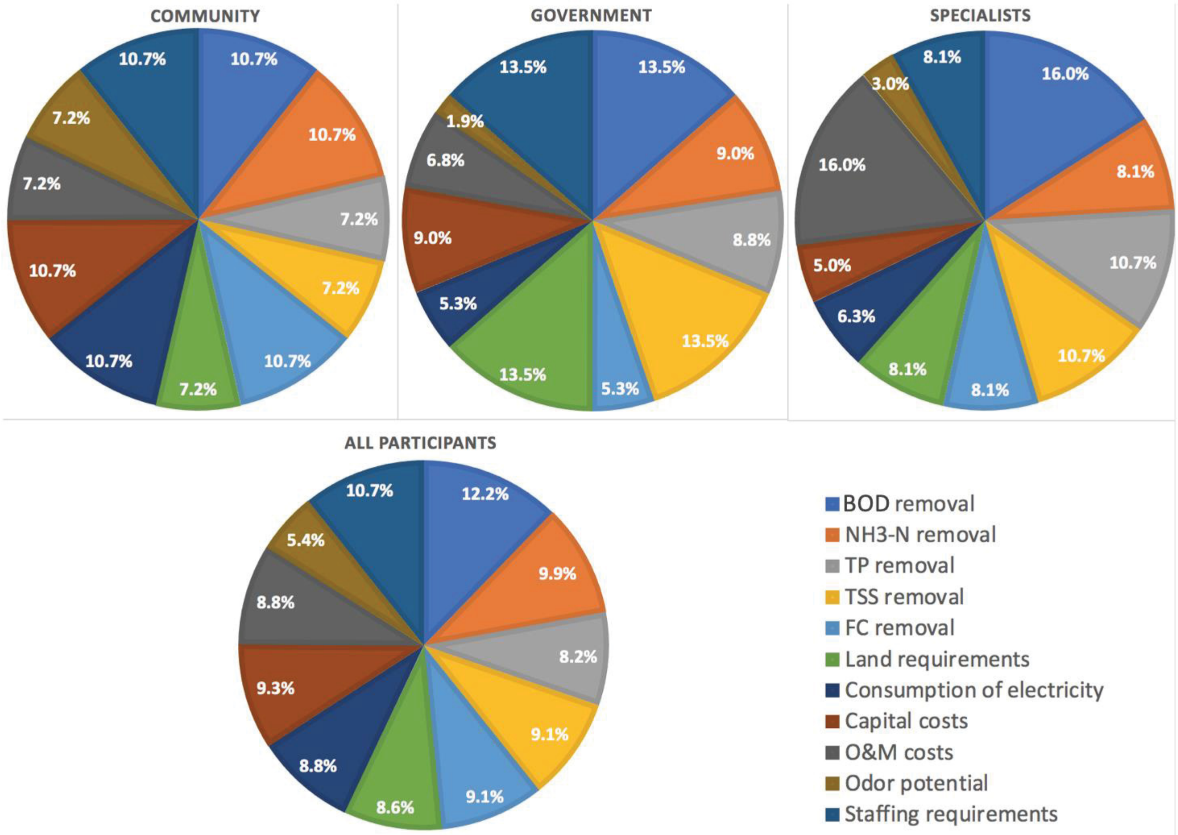
5th – PROCESS EVALUATION

Summing up, the operation of this step has resulted in the evaluation by applying the ValueCharts tool. Besides presenting the obtained results, the following subsection has also aimed to discuss the participants' perceptions by assessing their preferences.

a) Obtained results from the ValueCharts tool application

Figure 27 illustrates the breakdown of the users' preferences regarding each selected indicator in this study. As it can be seen, the four graphs were divided into groups, starting with the community, government, specialists and finally all of them collectively.

FIGURE 27 – GROUPS' PREFERENCES FROM THE VALUECHARTS APPLICATION



SOURCE: The author (2018).

As seen in Figure 27, the most addressed indicator by all participants are related to organic matter removals (in terms of BOD), representing an average of 12.2% of the total applications. It indicates concerns in protecting the environment in terms of discharging organic matter into the receiving water bodies.

Another relevant preference also within the environmental indicators and associated to all applicants is the 'NH3-N removal' (9.9%). This nutrient indicator is also responsible for inducing the process of eutrophication in the water bodies. The other environmental indicators have embodied a preference average of approximately 8.8% each.

Furthermore, by looking at the groups of participants separately, what stands out in Figure 27 are the relative differences of the 'odor potential' and 'electricity consumption' indicators. While government and specialist groups do not care for those, the community group is indicating distinct predilections.

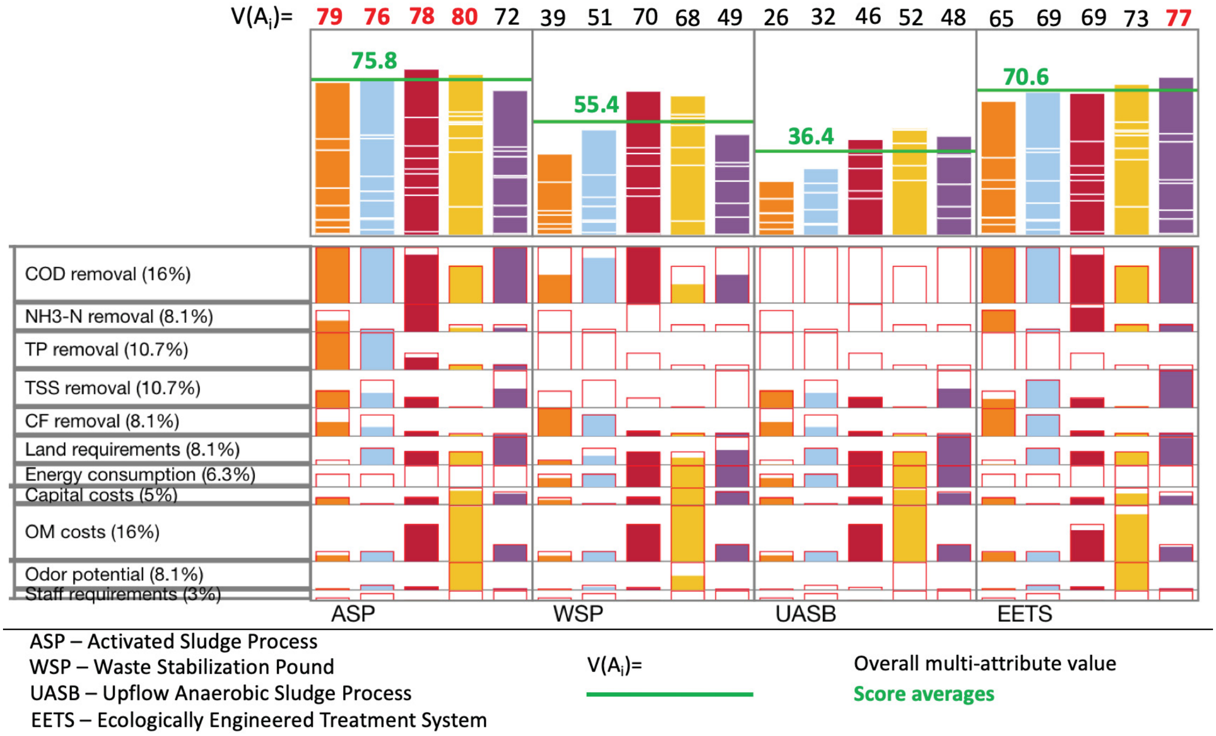
Regarding the 'odor potential', government and specialist groups are placing it as the least preferred one (2.4% on average), whereas community participants pay a relevant attention (7.2%) to it. However, one of the hypotheses was that the social indicators could be the most preferred from the application with the community group. Nevertheless, even considering that the ‘odor potential’ was relevant in comparison to the other two groups, and that the ‘staffing requirements’ has shown even more favorable appeal from the households’ participants (10.7%), environmental concerns still have taken more attention in general indicators’ concerns from the community. The BOD, NH_3-N and FC removals were also preferred with a 10.7% rate, for instance.

Another group that has notably weighted the ‘staffing requirements’ was the government group (13.5%). Even though this research has firstly assumed that the cited group would focus on economic aspects, this result is also coherent given the government’s social concerns.

In respect to the ‘electricity consumption’ indicator, the comparison also demonstrates an important contrast of 10.7% (community group) and 5.8% (on average by the other two groups). Given those results, it is highly likely that the community group is more concerned with the WWTS in terms of quality of life to their nearby areas. In the interview, when asked why they are concerned about the electricity indicator, many of the participants associated the possibility of paying higher power demand pass-through taxes.

Eventually, from the users’ preferences and the application of the ValueCharts, Figure 28, 29 and 30 present screen pictures of the tool and the obtained results. In other words, they show the interface of the result chart from each specific group of participants (e.g. specialists, government representatives and community). Each vertical bars and top values correspond to the final scores (Overall multi-attribute value) of a particular participant, which was obtained from the results of the equations as depicted in subsection 3.3.3.

FIGURE 28 – VALUECHARTS INTERFACE OF THE RESULTED CHART BY THE SPECIALIST MEMBERS



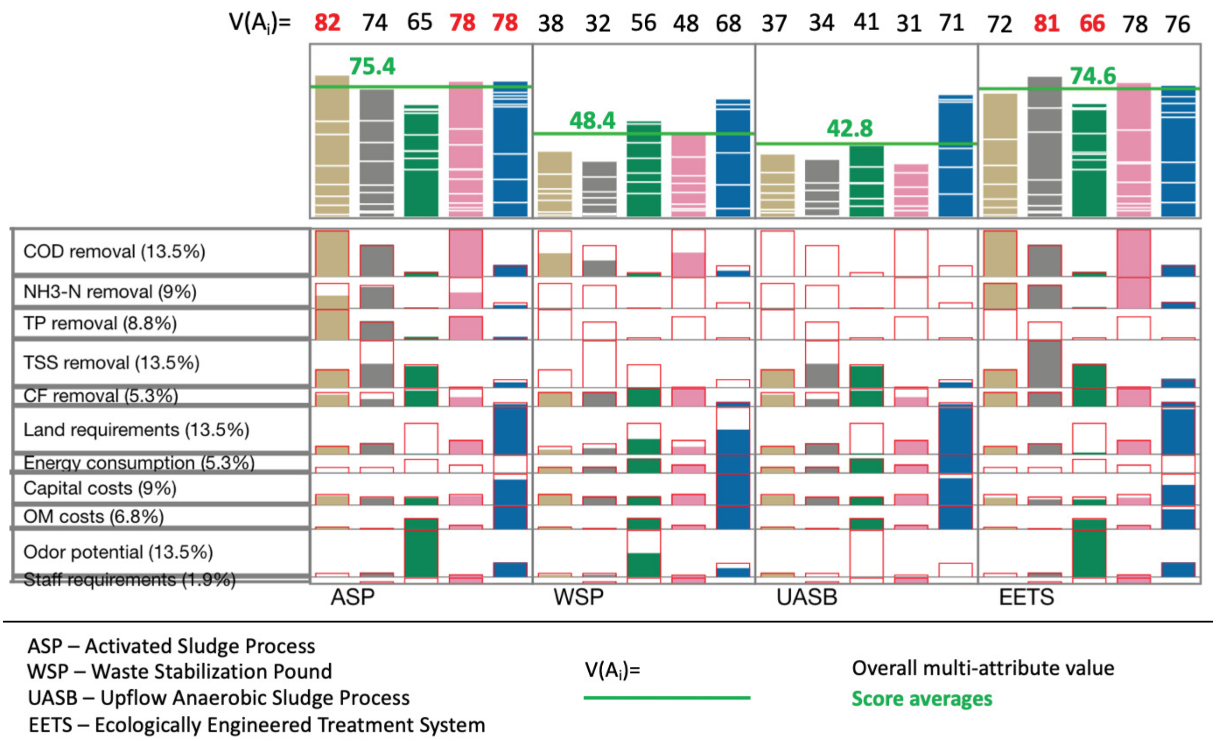
SOURCE: The author (2018).

As seen in Figure 28, the ASP has received the highest total scores (75.8 on average) by the specialist group, followed by the score of the EETS with 70.6, while the average of the UASB was the lowest (36.4). Indeed, the most weighted indicators by the specialist group are those inserted within the environmental group. In this view, the ASP has shown high BOD removal performances, as well as in terms of nutrients removals (for details see Table 25). Nevertheless, the UASB (not followed by any post secondary), has presented acceptable or insufficient efficiency based on the preferences of the same parameters, which indicate why it has not received relevant score in the evaluation analysis.

Another important aspect is that EETS was the second highest scoring WWTS alternative by those cited participants. Certainly, because of its similar characteristics to the ASP and hence the high performances related to removal performances. Notwithstanding, the EETS has received a slightly less total score than the ASP given the fact that the performances are related to ‘phosphorus removal’ and ‘O&M costs’ indicators. The specialists have given significant weight for these two indicators, and the ASP’s performances are superior for both parameters.

Figure 29 introduces the opinion and weights of the government group of participants.

FIGURE 29 – VALUECHARTS INTERFACE OF THE RESULTED CHART BY THE GOVERNMENT REPRESENTATIVES' MEMBERS



SOURCE: The author (2018).

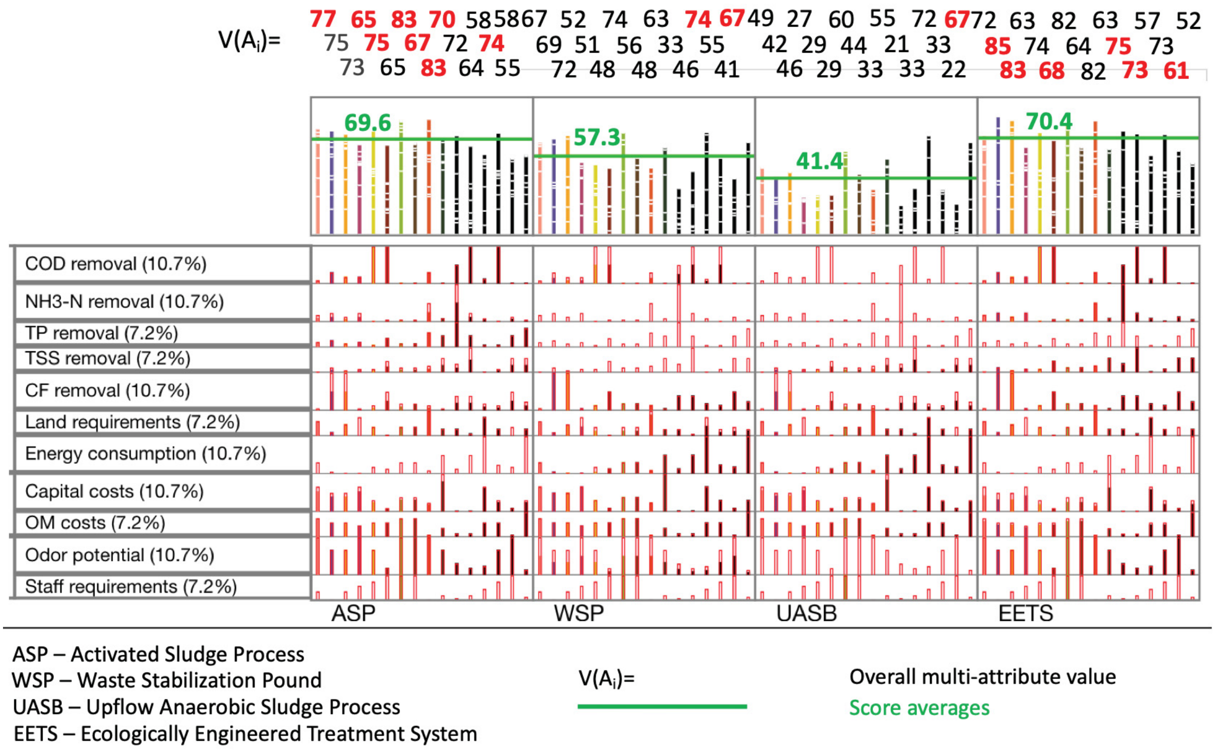
As it can be seen in Figure 29, the results from the government representatives follow the same tendency in terms of the highest and the lowest scoring WWTS alternatives as the specialists. Indeed, both ASP and the UASB have taken the opposite positions in the hierarchies (top and bottom, respectively). The averages have summed 75.4 and 42.8, respectively. In spite of the fact that the government participants have also rated BOD and TSS removal indicators as the highest preferred ones, what can be extracted as a difference from the group of specialists is that they are also highly concerned with 'land requirements' and 'odor potention' factors.

Those considerations have led the results to the same pattern in terms of the winning alternative as previously depicted. Although, the difference of the scores between the ASP and the EETS decay mainly because of the performances' rates of relevant weighted indicators for each case. For instance, the performance of the 'O&M expenses' indicator (relevant within the specialists' analysis) was 4 times better for the

ASP in comparison to the EETS. In the case of land requirements, 3 times better considering the same comparison.

Subsequently, Figure 30 presents the preferences of the community group.

FIGURE 30 – VALUECHARTS INTERFACE OF THE RESULTED CHART BY THE COMMUNITY MEMBERS



SOURCE: The author (2018).

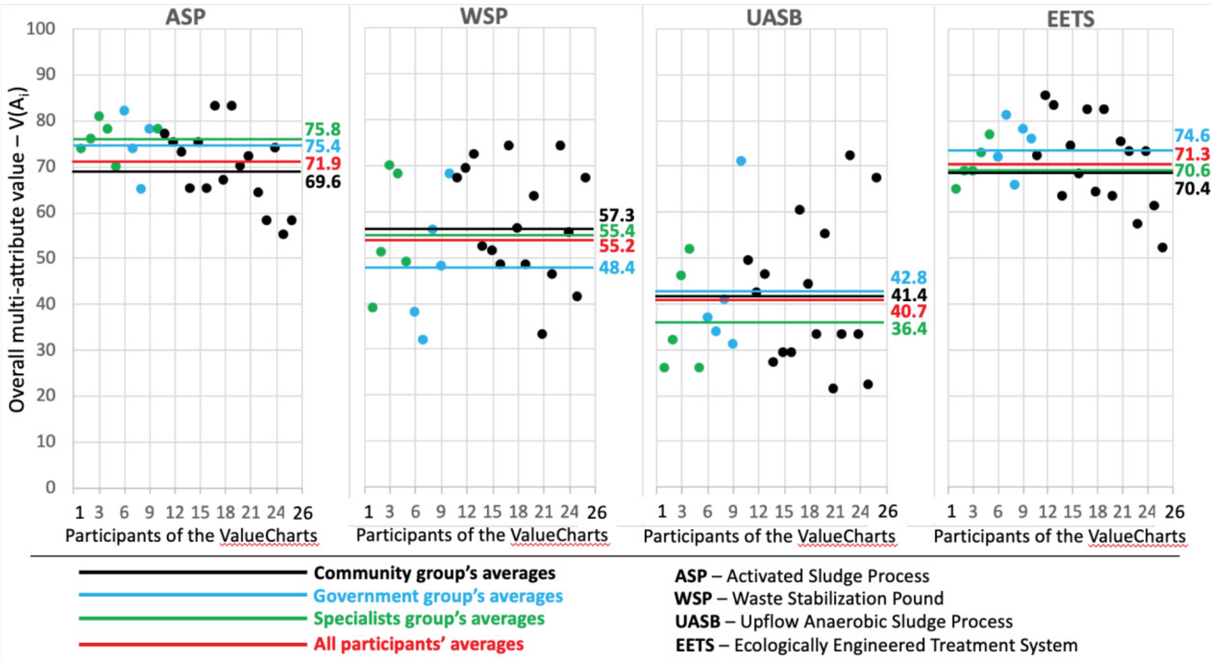
In this case, the tool application by the community participants has resulted in the EETS as the WWTS alternative highest scored. The average score of the EETS was 70.4 in this case, against 69.6 of the ASP. A minimum difference was found between the first and second highest scoring alternatives in comparison to the previous group's analysis.

Meaningful differences that make those alternatives' scores closer to the community participants could be observed. One of the reasons is that the weights given by the members of the community group are more balanced, wherein the preferences' differences drop to 33%, at maximum (i.e. 10.7% and 7.2%). Moreover, the most weighted indicators have ranged in 10.7%, and it repeats in 6 different cases, in particular three of them within environmental concerns (BOD, NH3-N and FC removals).

Continuing approaching the community participants, even though the ASP alternative has presented better performances in terms of economic indicators, which makes it the leader in almost all the cases, the efficiency for 'NH_3-N' and 'FC' removals are worse in comparison to the EETS. These are other reasons why the differences between those two alternatives have droped. In the same vein, the UASB has received the lowest scores and stands in the last position in comparison to the others.

Subsequently, the application of the ValueCharts tool by all applicants has resulted in the summarized total scores, as presented in Figure 31.

FIGURE 31 – SUMMARY OF THE OUTCOMES FROM THE VALUECHARTS TOOL APPLICATION



SOURCE: The author (2018).

The outcomes of Figure 31 indicate that the ValueCharts tool presents similar bias when comparing all groups and their averages. Hence, it shows that there is a tendency to score aerated systems (i.e. the ASP and EETS), with scores around the ranges of 70 and 75. Additionally, all groups were consistent in not scoring the anaerobic treatment (UASB) alternative, which total scores have been stationary near to 40.

Therefore, these results indicate an important advantage in pointing out the quality of the effluent to be discharged in water bodies by examining all participants' judgments. In other words, it corroborates the propensity fot WWTS alternatives to succeed, which bear more efficient processes in terms of environmental characteristics removals.

In some way, that previous discussion also implies why the UASB alternative has received fewer scores in comparison to other WWTS alternatives (Figure 31). However, it is important to interpose that this study has not considered UASB treatments together with post-secondaries devices. In spite of the fact that it would certainly increase the costs, they could be more competitive in this acknowledge comparison due to higher efficiencies in terms of wastewater characteristics removals.

Notably, the ASP was the winning alternative in all cases. However, as it is discussed in the next section, further analyses have shown important outcomes and conclusions that may lead to other judgements too.

Finally, it is important to highlight that this research has not presented a screen picture of the ValueCharts tool application with all tool participants given that the score results would not be legible when printing the screen.

6th – RESULTS ANALYSIS

This section has firstly focused on discussing the final WWTS outcome – i.e., the winning alternative from the application of the chosen DMA.

Secondly, a proposition of a first draft of an obtained suitable system from the application of the SDM instrument.

Thirdly, the assessment has targeted at examining the whole SDM process and additionally both PS-WWTS and ValueCharts tools. That is, if the tools have achieved their objectives in terms of: i) providing suitable and reliable responses by mainly considering the users' preferences; ii) taking into account visualization and interactiveness features in order to simplify and adequately democratize the application through the application of the questionnaires).

a) Final WWTS outcomes evaluation

In absolute terms, the ASP was the winning alternative from the application of the SDM instrument. Indeed, taking in consideration all applicants' preferences from the comparison process (ValueCharts tool), the results have shown important bias for systems that have had better environmental performances in terms of removal characteristics, mainly by the participants' predilections for the indicator related to organic matter removal.

Additionaly, highlighting the results and preferences' experiment from the point of view of the community group, for example, it might suggest that the most suitable WWTS alternatives should consider some aspects that are occasionally neglected in DMA, as approached for the scenario of this research. In particular, those connected to well-being and possibility of employment position in the nearby communities – i.e., odor potential and staffing requirements indicators, respectively.

Notwithstanding, some contrasted and explaned outcomes have exposed that another alternative might be suitable and be considered for the scenario defined. The EETS has relatively shown approximated scores in both separate and all participants' cases analysis, in particular in regard to the community group.

Considering the environmental removal indicators and adding other preferences from the view of the community group, the result has shown that the EETS alternative was the winner in the evaluation isolating this specific evaluation. Additionaly, it was the only analysis in which the evaluation has deviated the pattern, wherein the score difference between the first and the second (ASP) alternatives was only 0.8%.

Even though in absolute terms the highest scoring WWTS alternative in the application of the ValueCharts was the ASP, the preferences of different groups and hence the scored results have expressed important additional findings. Indeed, a complete analysis of the outcomes is not only to access a unique preferred alternative. Rather, it was illustrated that the whole assessment allows the decision-makers to focus on the distinction of preferences from different groups of participants and hence points of views.

Moreover, Table 29 summarizes the outcomes from the statistical analysis of the population sample.

TABLE 29 – STATISTICAL ANALYSIS OF THE POPULATION SAMPLE

n	N	σ	$Z_{\alpha/2}$	E
16	2,000	0.10	1.96	~0.049

SOURCE: The author (2018).

Thus, the results of the application of Equation 3 indicate that based on 95% of confidence and in the size of the sample, the difference between the average scores can be despised. In other words, the value of *E* is approximately 4.9%, lower than 5%, which indicates that the two highest scoring alternatives may be considered winners in the evaluation application.

b) Drafting of a suitable WWTS

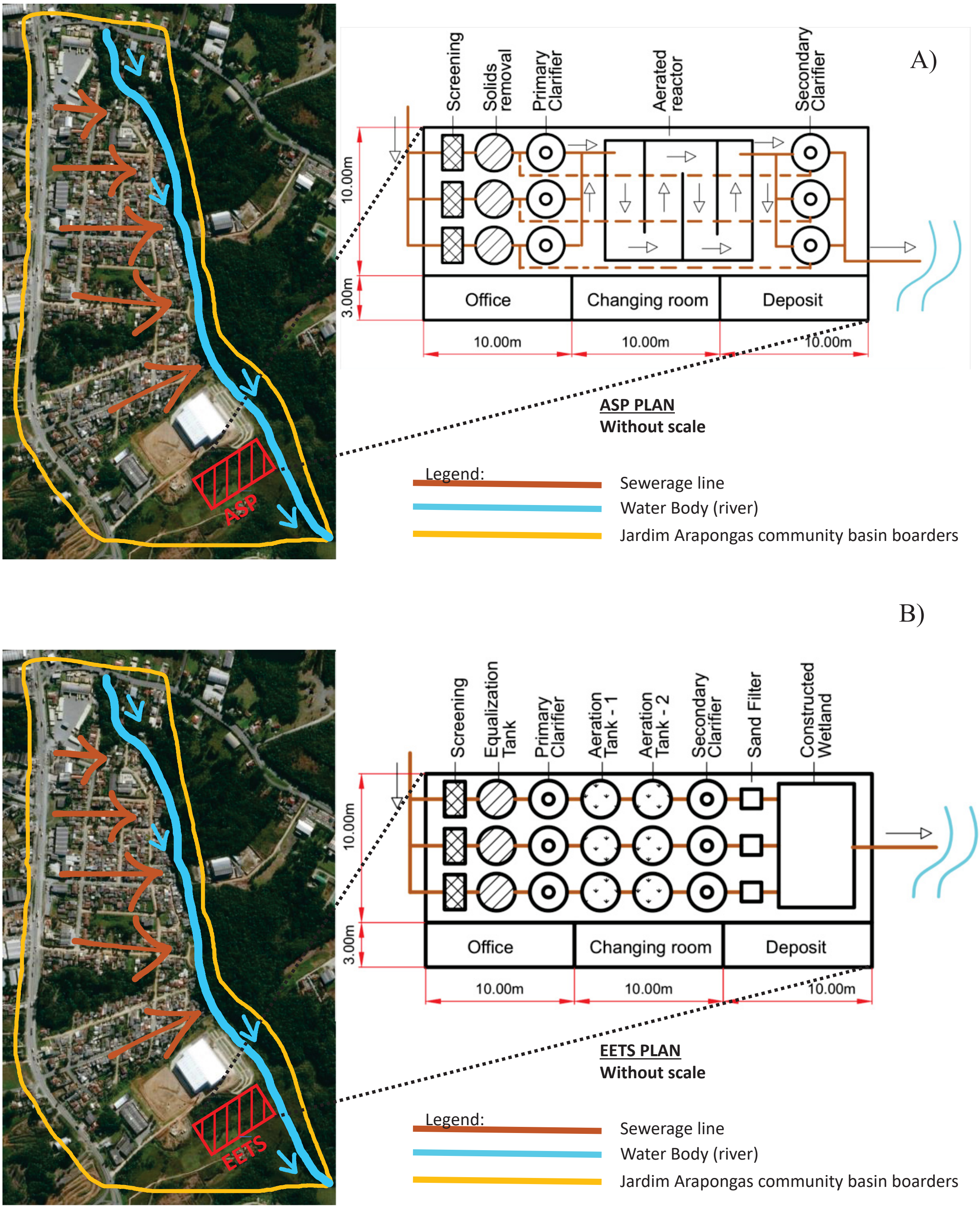
From the obtained results related to the most suitable WWTS alternative (as discussed in 5.6.2), the alternatives that acknowledge aerated treatment have received the highest scores. The main reasons are the fact that the users have preferred environmental indicators within the evaluation balance, in which better performances in those aspects have led the result for thoses types of systems. Additionally, aerated devices have also presented the best efficiencies regarding the control of odor potential indicator (another highly evaluated one).

In this view, as a community contribution, this research proposes WWTS drafting that could be implemented in the scenario based on the results from the applied DMA process. Therefore, two alternatives would be adequately recommended considering the preferences given by the users – i.e., the ASP and EETS.

The ASP was the mostly scored from the ValueCharts application. Still, the EETS was equally successful in comparison to the ASP, since they have similar characteristics in terms of removal efficiencies. Additionally, this research has evaluated the terrain and hydrographic scenario, and also this applied study considers population around 2,000 people. Nevertheless, as previously explained, harvesting and sludge management were not considered within the comparison process.

Therefore, this research has used the EETS framework presentation (as introduced in 3.2.7.3) and the information of the land requirements (from Tables 25 and 28) of the EETS in order to design the system's perimeters. Additionally, the treatment is composed of three modules in paralel in order to provide the possibily of maintenance in one of them when necessary. In this view, the final sketches are detailed in Figure 32.

FIGURE 32 – DRAFTING OF THE PROPOSED WINNING WWTS ALTERNATIVES FOR THE JARDIM ARAPONGAS AND ESPLANADA COMMUNITIES: A) ACTIVATED SLUDGE PROCESS (ASP); AND B) ECOLOGICALLY ENGINEERED TREATMENT SYSTEM (EETS)



SOURCE: The author (2018).

Figures 32-A and 32-B present potential sites of the highest scoring WWTS alternatives by the application of the evaluation. As it is seen, for both cases the location of the systems considers downstream factor within the community basin, hence favoring the gravity component and also reducing pumps infrastructure. Additionally, it is an unoccupied area that easily allows the construction of the systems.

Turning now to the devices' approaches, the dimensions (as depicted in Table 30) have contemplated the capacity of the commonly designed Hidraulic Retention Time (HRT) of 0.5 and 1.5 days, for the ASP and EETS respectively. The total sewage volume is 300 m^3.

TABLE 30 – ASP DEVICES' MEASURES

Device	Measures
ASP (HRT = 0.5)	
Screening	1.0 m^2
Solids removal	45.0 m^3
Primary clarifiers	60.0 m^3
Aerated reactor	135 m^3
Secondary Clarifiers	60.0 m^3
EETS (HRT = 1.5)	
Screening	1.0 m^2
Equalization Tank	25.0 m^3
Primary Clarifier	25.0 m^3
Aeration Tanks (two devices in series)	25.0 m^3 each
Secondary Clarifier	25.0 m^3
Aeration Tanks (two devices in series)	25.0 m^3
Sand Filters	2.5 m^3
Wetland	20.0 m^3

SOURCE: The author (2018).

The next subsections are divided in topics that present the final assessment of the application of the whole SDM process and tools. In particular, the main observed achievements and possible improvements by the manager and users in regard to DMA and both proposed tools.

c) SDM Analysis

The adapted SDM instrument of this research has demonstrated feasibility to be accomplished. Despite being partially adapted, all original SDM steps, as depicted in Gregory et al. (2012) and presented in the material and methods chapter, were performed accordingly.

The only operation of the cited genuine DMA that could not be implemented here was related to the cyclical framework. As the structure considers a circular flux of activities, this research has only achieved up to the adapted sixth step, and hence left possibilities to continue the study subsequently.

In this view, the application of the SDM instrument has been demonstrated as achievable, since it has permited for the information of each step to conveniently feed the subsequent one. In other words, the manager could easily flow from basic and organized information regarding a complex decision context to a final interactive and visual evaluation step.

Table 31 presents important findings and opinions from the participants through the questionnaire application. The information is related to the SDM.

TABLE 31 – SUMMARY OF THE SDM OPINION OBTAINED FROM QUESTIONNAIRE

	Rate of participants who…			
	CG (16 participants)	**GG (5 participants)**	**SG (5 participants)**	**Total**
…feel relevant his/her participation in the DMA process concerning sanitation approaches	100%	100%	100%	100%
…have already participated in a similar DMA process	0%	20%	40%	~12%

NOTES: CG – Community group; GG – Government group; SG – Specialist group; DMA – Decision Making Analysis.
SOURCES: The author (2018).

As seen in Table 31, all participants were comfortable to engage in the DMA process of this study. A relevant matter is concerned to the community participants. The whole group felt their opinions relevant, despite the inherent complexity (in many times related to technical approaches which they usually do not have expertise). Therefore, it indicates that the process might be considered achievable within a vast and diverse group of participants.

Moreover, a few percentages of the participants have already participated in other DMA processes, approximately 12% of the total (3 persons amongst 26). Amongst the cited processes, some participated in the evaluation analysis of water and wastewater management for municipalities, being one specialist and one government representative. Another participated as a manager of a DMA process.

Turning now to another relevant aspect related to the feasibility of the instrument, is the insertion of the proposed tools. Summing up, it might be said that both PS-WWTS and ValueCharts tools have supported the SDM instrument. In this view, there are innumerable forms to pre-select alternatives. For instance, the manager can directly gather from participants and interviews, applying questionnaires, etc. Nevertheless, the PS-WWTS has come to facilitate this pre-selecting step to the manager who can use the cited tool, as seen in the next topic. Likewise, the ValueCharts also appears to simplify the evaluation step. Although there are other possibilities for evaluating alternatives, the tool has proved useful also in terms of the same features.

Conclusively, the application of the SDM has been revealed feasible since it could be conveniently applied with a diversified group of participants (e.g. specialists, government representatives and community). People with distinct educational levels, who could participate in the process by giving their preferences and hence accounted in the final result.

d) PS-WWTS tool analysis

This topic presents the analysis regarding the PS-WWTS tool usability and possible insertions that could benefit the process. They were obtained from the observation at the moment of the application of the cited tool by the researcher and from the impression of the specialists participants in the questionnaires.

It was noticeable that the PS-WWTS have made part of an important step of the DMA. It has allowed the final evaluation process with a limitated number of alternatives in order to make the decision analysis more practical.

Additionally, the layout of the tool and the internal steps have made the usability also worthwhile. As depicted, it was subdivided in only three stages in order to be coherent with the pre-selection pragmatic idea. Indeed, the three main available characteristics of a built scenario are truly basic and definitely have the function of excluding systems that are not applicable to that case. Moreover, the obtained results have shown that they were not jeopardized since it was proved that the obtained set of WWTS alternatives was consistent with the most applicable ones into similar scenarios.

On the other hand, the first highlighted gap element in regard to the cited tool is concerning integration. In other words, the most pre-defined set of WWTS alternatives by the group of selected participants could be automatically exported to the ValueCharts tool. Given that the ValueCharts tool has a feature of importing a specific structure of cells within a XML format file to generate an evaluation analysis, achieving that would only be possible by adapting the outcomes of the tool in a way that the users could save the chosen alternatives in that XML structure. Additionally, this feature proposal would be feasible if the tool could also carry out a performances' database of each available WWTS alternative.

Another important intrinsic aspect in respect to the proposed features is to allow users to define the indicator that is going to be used in the evaluation step. This possibility would permit another effective participation of the users and hence return a more coherent process in terms of users' preferences. Remembering the method of this research, the indicators definition has acknowledged the representativeness mechanism.

Moving towards the obtained information from the questionnaires regarding the PS-WWTS application, most of the users have never used a pre-selection tool in other DMA process; only one of the participants have cited a similar tool, the "Multi-Criteria Spreadsheet". As stated by the participant, it was considered adequate and acknowledges environmental, economic, social and operational groups of indicators.

Table 32 shows relevant results regarding the usability of the PS-WWTS tool.

TABLE 32 – PS-WWTS TOOL OPINIONS

Participants who…	Total
1. In relation to the first PS-WWTS's stage (basic characteristics of the scenario)	
…strongly agree to the three basic variables (Application level, Urban characteristics, Input loads)	100%
…believe that three basic variables as the PS-WWTS is the optimal quantity	60%
…admit that five or more basic characteristics is advantageous	40%
Cited basic characteristics: "Implementation and O&M costs";	40%
"Depuration capacity of receptor water bodies";	20%
"Land requirements";	20%
"Environmental licenses";	20%
"Operator training"	20%
2. In relation to the stages of the treatment and their respective devices	
…admit that the preliminary treatment devices are adequately displayed	20%
Cited 8alternative preliminary devices: "Parshall flume"	80%
…declare that the primaries, secondaries, post secondaries and tertiaries treatment devices are adequately presented	100%
Additional stages of treatment: Sludge handling	20%
3. In relation to the pre-selection of WWTS criteria	
...agree or strongly agree with the technical criteria for pre-selecting WWTS alternatives	100%
…agree or strongly agree with the representativeness criteria for pre-selecting WWTS alternatives	20%
…strongly agree to use the PS-WWTS to pre-select WWTS alternatives	100%
4. In relation to the usability of the PS-WWTS tool	
…consider satisfactory or strongly satisfactory the usability in terms of the visualization and interface criteria	100%
Additional coments: "Regional language version"	20%
"Integration with the following steps"	20%
"Help support button"	20%

SOURCES: The author (2018).

Assessing the data from Table 32, firstly concerning the first stage of the PS-WWTS related to the basic characteristics of the scenario, all participants have recognized the importance of, at least, these three variables (Application level, Urban characteristics, Input loads). However, some users have also mentioned that additional characteristics could be used. For instance, the implementation and O&M costs and land requirements components, in spite of the fact that they have already been part of the indicators of the subsequent evaluation process.

What stands out from those specific cited variables is that none of the users have not realized those indicators in the fifth step of the SDM or felt that they should be more important in the pre-selection. Although, this research has perceived that it would be more convenient to employ those indicators in the evaluation step, in order to not exceedingly limitate available WWTS alternatives in the pre-selection step.

Moreover, another basic characteristic, the 'depuration capacity of receptor water bodies', was mentioned by the users. Although it may vary for each scenario, it seems to be a valuable one that could be adapted to be forwardly inserted in the PS-WWTS tool, since it can also support elimination of alternative possibilities. The remain 'environmental licenses' and 'operator training' variables can be certainly considered specific for each territory.

Secondly, a range of 80% of the participants of the PS-WWTS have argued about the Flow Measurement (or Parshall Flume) device absence. Indeed, this cited device is not only well-known for the chosen scenario, but also worldwide. However, this study has developed the PS-WWTS mostly based on a similar tool, which has also not considered this preliminary device.

Moreover, in 20% of the applications it was pointed out the fact that the tool presented lack of dealing/treating sludge. It was relevantly argued that this stage might be relevant given the characteristics of the scenario. Certainly, it would be. Notwithstanding, the main focus of this research was not to simply define an absolute WWTS, but rather on an instrument to support the analysis, in which future works could consider the sludge concern.

Thirdly, all five users have agreed or strongly agreed that technical criteria should mainly lead the definition of the pre-selected alternatives, but only one has also strongly agreed that representativeness criterion was relevant. In the applied study of this research, repetition of built treatment systems and comparison with the most used ones in similar scenarios were assumed for pre-selecting the set. Additionally, in general the participants have expressed their interests in using the PS-WWTS tool.

Fourthly, in terms of the tool usability, all participants have considered the tool user-friendly in terms of its visualization and interface features. Indeed, the tool provides three stages that integrate themselves for building pre-WWTS alternatives for the specific conceived scenario.

Finally, three suggestions were provided: 'regional language version'; 'integration with the following SDM steps' and 'help support button'. Naturally, a tool that encompasses local language may reach more users. In the same vein, a help support button can assist the users in possible difficulties when the manager is not available at the application moment. However, in this application study, the PS-WWTS tool was applied only with specialists in the presence of the manager.

e) ValueCharts tool analysis

This topic has acknowledged the analysis of the ValueCharts tool application. In the same vein of the previous topic, the point of view of the manager of the decision analysis is firstly presented. Secondly, the assessment has focused on the impressions of the tool participants. This second assessment has only encompassed the perspectives of the users from the two groups that have indeed applied the ValueCharts – i.e., specialists and government. The investigations have totalized ten inquiries.

Therefore, firstly focusing on the manager's point of view, the ValueCharts tool has shown highly usability not only for providing a simple and better alternative result, but it has also demonstrated capability to easily gather users's preferences and present them in a visual way, so that the comparisons could efficiently show additional conclusions in terms of the obtained results. As depicted in Subsection 5.5.2, even though the scores results have indicated a winning alternative (ASP), the visual similarities in terms of users's weights, and summing those with the intrinsic characteristics of the second most scored system (EETS), have made it also suitable for the scenario selected.

In the matter of the recognized gaps, as stated before, the integration of the PS-WWTS (3rd step of the SDM) could provide a practicability to the whole process. Considering this feature, the manager of the process would not need to waste time by seeking and inserting info related to the alternatives' performances after the application of the 3rd step. Hence, it would let the application more rapid since both tools could be applied at once with the same participants.

One important issue that has standed out in this applied study was to analyse outcomes from application with a great number of participants. For instance, applying the tool with a group of more than 15 participants has made the tool troublesome in terms of visualizing the outcomes. As observed in Figure 30, the layout of the web tool in this applied study seems to be polluted given the considerable number of preferences/users/alternatives shown.

However, there is a ValueCharts tool's feature that seeks to access and easily visualize a smaller group of participants. That is, the "mark/unmark" check button option, wherein only the manager can select or deselect specific users. This procedure has conducted this research to obtain the results of the 5.5.2 subtopic.

Another relevant issue of the application was related to the 1st user interface of the tool. That is, the format of ‘defining score functions’ – i.e., inserting the weights in regard to each indicator. Some difficulties were found in relation to the available fractions between 0 and 1 related to maximum and minimum preferences, respectively. It has brought some complicated occasions at the time of the tools’ tutorial given by the manager.

Concluding the observations about the manager, the use of the proposed ValueCharts tool has demonstrated the possibility of easily and clearly extracting the main predilections of all participants and groups of users separately and hence discuss them cyclically in order to obtain one suitable solution, or even more.

Now turning to the assessment of the aplicants’ viewpoint, Table 33 summarizes the outcomes of the investigation of the ValueCharts tool stage, wherein ten participants (from the specialist and government groups) have filled the questionnaires.

TABLE 33 – VALUECHARTS TOOL OPINIONS (SG, GG)

Participants who…	Total
1. In respect to the number of indicators of the evaluation process	
…agree that 5 to 10 indicators is the best amount of variables	10%
…agree that 11 to 15 indicators is the best amount of variables	70%
…agree that 16 to 20 indicators is the best amount of variables	20%
2. In respect to the evaluation of this applied study indicators	
…agree or strongly agree with the defined set of environmental indicators in ValueCharts	100%
Additionaly agreed or strongly agreed indicators that could be inserted in the defined environment set, by the majority of the participants: Greenhouse gas emissions, Chemical consumption for the treatment, Byproducts reuse, Availability of material and components of the WWTS, Sludge production, Available area to expand the system.	51% or more
…agree or strongly agree with the defined set of social indicators in ValueCharts	100%
Additionaly agreed or strongly agreed indicators that could be inserted in the defined social set, by the majority of the participants: Acceptance, Size of community served, Local waterborne diseases, Population density	51% or more
…agree or strongly agree with the defined set of economic indicators in ValueCharts	100%
Additionaly agreed or strongly agreed indicators that could be inserted in the defined economic set, by the majority of the participants: Land costs, Availability of funds	51% or more
3. In relation to the usability of the ValueCharts tool	
…consider satisfactory or strongly satisfactory the usability in terms of the visualization and interface criteria	100%
…consider satisfactory or strongly satisfactory the feature of restating the preferences	
Additional coments: “Help support button”	10%

SOURCES: The author (2018).

As also seen in Table 33, an inconsistency can be highlighted, and it is related to the optimal number of indicators that should be considered in the evaluation process. Despite the fact that most have considered that the best amount is between 11 and 15 indicators, in approximately 85% of the questionnaires the participants have agreed or strongly agreed with more than 20 unities that could be inserted in the tool. In other words, although the previous questionnaire's question has tried to orientate the answer of the following question, based on the encompassed defined amount, the users have felt inclined to select a bigger set when confronted with other indicators.

In this view, although in all answers the users have agreed with the defined and entire set of indicators, Table 32 shows other preferred ones that could also be part of the evaluation.

Firstly, in relation to the environmental group, greenhouse gas emissions, use of chemical and byproducts (e.g. sludge and gases) generated plus reuse were all added as possible indicators that could be included in the evaluation process.

Regarding social aspects, indicators such as alternative acceptability, amount of people benefited from the treatment implementation and local waterborne diseases have also been cited as favorable to be inserted in the set by the participants.

Concerning the economic approach, costs of land and availability of funds were agreed and strongly agreed to be part of the tool's set. Indeed, the land costs is important since it importantly modifies the implementation costs. Similarly, funds availability is also a relevant indicator. However, since it may be considered analogous to the already used costs indicators, the last cited indicator could conveniently be disregarded given the overlaps avoiding factor.

Another interesting finding is that user partipation in the definition of indicators is conceivably achievable. However, their performances for all evaluated treatment systems should be previously feasible. Moreover, the cited user cooperation denotes reliability to the whole process since it considers the participation also in the creation of the evaluation process, as contemplated in the definition of the pre-selected WWTS alternatives step.

Conclusively, an additional comment was presented in only one questionnaire: the 'help support button'. Similar to the suggestions that have aimed at the improvements of the PS-WWTS tool, this cited help feature may assist the users in the case of doubts and the absence of managers at the application moment.

6 CONCLUSIONS

This chapter not only presents the conclusions of the outcomes from the application of this research's proposals, but also the discussion of the hypothesys, the study's limitations and the possible future contributions.

6.1 SUMMARY AND MAIN OUTCOMES

This study has explored the development and application of an adapted Structured Decision Making (SDM) by including the pre-selection of wastewater treatment system (PS-WWTS) and ValueCharts tools for selecting suitable WWTS alternatives into a generic scenario.

Firstly, the SMD is a cyclical DMA used to support complex decisions with many indicators and alternatives under uncertainty, such as in the field of environmental engineering and also related to sanitation approaches.

Secondly, the also developed PS-WWTS is situated within the third step of the SDM and incorporates techniques of interface with the users by collecting basic characteristics of a scenario and pre-select correlated WWTS alternatives. In other words, it allows the users to design elementary configuration of the Wastewater Treatment Systems (WWTS) pre-alternatives.

Thirdly, ValueCharts is located within the fifth step of the proposed SDM instrument and has the distinguishing characteristic of performing the evaluation process. It is achieved by comparing scores based on users' preferences and performances of a pre-selected set of WWTS by considering user-friendliness and visual interactiveness features.

In this view, all the cited instrument and tools were combined and successfully applied within an evaluation into a peri-urban community in Brazil, wherein the results have shown the following specific conclusions.

With regards to the indicators, the design was digging sources such as peer-reviewed papers in the field of support decision and domestic sewage treatment, wherein this research replicated the mostly studied and mentioned indicators.

Specifically related to the PS-WWTS application, the set of pre-selected WWTS alternatives (in the majority) was based on criteria of representativeness of the WWTS mostly designed by users and widely implemented. In the scenario selected, they were the Activated Sludge Process (ASP), Waste Stabilization Pond (WSP), Upflow Anaerobic Sludge Blanket (UASB), and Ecologically Engineered Treatment System (EETS).

From the ValueCharts application, the ASP has represented the highest scoring alternative between the pre-selected ones by the entire group of users of the ValueCharts tool. Still, the results have shown additional findings when individual groups are analysed. For instance, the EETS was also highly scored by the community group, given preferences correlated to social aspects, i.e. – odor potential and pass-through taxes. In the same vein, the study has demonstrated the importance of considering the community group who is often excluded from DMA in sanitation.

Therefore, from the insights gained by the SDM application, a relevant one is that an analytical comparison between the integration of performances database of pre-defined treatment systems and users' preferences can easily narrow down suitable alternatives.

Moreover, the outcomes from the ValueCharts tool application have presented a tendency when comparing the averages of all groups of participants. Indeed, it has shown that there is a tendency for scoring aerated systems (i.e. the ASP and EETS), in which the scores have gone between 70 and 80 points. What it means is that the users were seeking for systems that acknowledge higher performances of removals in particular in terms of organic matter as well as other environmental characteristics of the wastewater (e.g. nutrients, solids and bacteria). Hence, no groups have scored the UASB treatment alternative, whose total scores have been stationary nearly to 40, given the same mentioned reasons.

Repeatedly, although the winning alternative was the ASP, a complete analysis cannot be made only to access a unique preferred solution. It was illustrated that the whole assessment allows the decision-makers to focus on distinguishing preferences from different points of view, and therefore reach other suitable solutions as well.

Furthermore, based on the experience of the participants, and rather importantly, their given preferences, the highest scoring systems were easily visualized after the interaction with the tools. Corroborating this statement, the applied questionaires have indeed found that the visualization and interactiveness techniques were significant.

Finally, the application has also easily and organizedly followed well-known engineering steps to address the definition of WWTS for a general community, and hence uncomplicated to be forwardly replicated. Summing up, the results have definitely demonstrated the obvious benefits of using the developed instrument and tools.

6.2 HYPOTHESES

This topic has focused on testing the hypotheses as depicted in Section 1.5. Therefore, those were restated in Table 34, wherein each one was completely analysed.

TABLE 34 – NULL AND ALTERNATIVE HYPOTHESES CONCLUSION

	H_0: Null Hypotheses	**H_1: Alternative Hypotheses**		**Evidences**
SDM Instrument and tools usability	Complex decision content requires advanced background of the user and complex instruments and tools	Complex decision content does not require advanced background of the user and complex instruments and tools	H_1	Non-specialists easily provide coherent and relevant preferences
	Visual and interactive are strong motivations	Non-visual or non-interactive are strong motivations	H_0	Friendly tools favor users' participation
Specialists Group	Heavily biased in the environmental group of indicators	Non or uncertainty biased on specific group of indicators	H_1	Biased in environment and economic groups
	The participation in the DMA is relevant	Neutral relevancy in the DMA final outcomes	H_0	Specialist users provide important outcomes
Community Group	Heavily biased in social group of indicators	Non or uncertainty biased on specific group of indicators	H_1	Balanced bias of the three groups
	The participation in the DMA is neutral or irrelevant	The participation in the DMA is relevant	H_1	Community users provide important outcomes
Government Group	Heavily biased in economic group of indicators	Non or uncertainty biased on specific group of indicators	H_1	Biased in environment and economic groups
	The participation in the DMA is relevant	Neutral relevancy in the DMA final outcomes	H_0	Government users provide important outcomes

NOTE: DMA – Decision Making Analysis
SOURCE: The author (2018).

The hypotheses have concerned the usability of the tools in terms of whether or not to collect the information from the users. All assembled information from those three groups of participants have demonstrated that the visual and interactive characteristics of the tools are indeed capable of representing reliable outcomes from users' preferences.

Summing up, the central questions here are: Might the tools be considered user-friendly and adequate within the decision making process in the view of the participants, and hence may support the whole process? As seen in the hypotheses' evidences, yes, it might.

6.3 LIMITATIONS OF THE STUDY

6.3.1 Related to the SDM Instrument

This study was limited by the absence of performance of the data analysis from existing systems of the chosen scenario. Firstly, in the view of the cited conventional systems (i.e. ASP, WSP and UASB), the obtained results related to the perfomances could indicate different outcomes. For instance, considering a tropical country such as Brazil, wherein the mean climate ranges are about 15^{o}C all over the year, the removal averages for organic matter for anaerobic WWTS could result in higher eficiences, and hence modify the calculations within the ValueCharts model. It is important to highlight that the averages used within the SDM process of this research were collected from studies in several climate sources, including subtropical scenarios.

Users' preferences can be biased by some factors, for instance, gender, age, income, etc. As an example, differentiating income indicator within the same group of participants may change the results. In particular, in developing countries wherein different profit rates are directly related with the educational levels of the population.

On one hand, people who have had more experience within environmental approaches in their scholar formation could hence aim their preferences at environmental parameters removal, for example, given the knowledge regarding the importance of the quality of the ecosystems.

On the other hand, households who have not had much involvement in those aspects, may direct their predilection to social aspects. Even though those factors were approached in this study through the application of the questionnaire and structured interview, that information has not made part of the ValueCharts tool. This feature within the ValueCharts would generate important outcomes given the visualization and interaction characteristics of the tool.

In regard to the EETS alternative, it occurs the same as to the removal of wastewater indicators in respect to the tropical climate. Additionally, other important variations are about the costs. In this view, even though the labor costs for the construction of the systems are usually higher in the developed countries given the qualified workforce, other costs – i.e., material and WWTS designs – could result in distinct implementation and O&M costs.

6.3.2 Related to the PS-WWTS tool

An important aspect in the field of decision making for WWTS alternatives, which was not approached in this study, was sludge and gases handling. In other words, this part of the research has focused on presenting possibilities for building pre-selected WWTS alternatives by tertiary treatment devices within the PS-WWTS tool.

Despite the importance of those aspects of treatment, the faced obstacles were associated to the difficulties in obtaining the performances of the set of the pre-selected WWTS alternatives. This condition could modify the results given the differences of performances regarding bio-solids generation of each system evaluated.

From the obtained users' concerns after the PS-WWTS application, some have acknowledged other basic characteristics of the scenario, for instance, the 'depuration capacity of receptor water bodies' could also be added in the tool.

In addition, the same lack of efficiencies of the pre-selected ones was also the reason for ignoring the aspect of reusing subproducts. Again, the final pattern of outcomes from the evaluation application (5^{th} step of the SDM) could be changed because of the different performances of each type of system.

6.3.3 Related to the ValueCharts Tool

An important factor not considered in the approach of this tool was the combination of different WWTS in the secondary stage of treatment. For instance, UASB reactors themselves produce effluent that usually do not comply with most discharge standards worldwide. Nevertheless, UASB plus Trickling Filters or

Facultative Ponds generally present more satisfactory results in terms of environmental characteristics removal.

Another one was the difficulty to input preferences within each indicator of the ValueCharts. In this process, the users were required to insert their preferred ranks between 0 and 1 for each indicator. Especially within the governement group, wherein the formation background was quite disparate, some confusions were detected, and the explanation needed to be more detailed and also extended.

6.4 FUTURE WORKS

6.4.1 Related to the SDM

A SDM future work possibility is to link the pre-selection alternatives with the evaluation process. This integration could benefit the analysis in terms of agility and pragmatism of a complicated content as approached in this research, hence allowing the manager to apply both steps at once in the investigation.

In other words, there are recent instruments and tools that have been approaching data knowledgment rather than focusing on visual and interactiveness analysis. The combination of the PS-WWTS and these types of tools (e.g. the ETEX), to be further on inserted in the ValueCharts, represents a gap not advanced in this study.

Another direction that might be fruitful would be the application of the cyclical SDM process. As depicted in the SDM structure section, the round framework allows inserting information into each step that usually contemplates relevant concepts obtained from the users' feedbacks. For instance, the method of defining the set of indicators could be different. This attitude might be important since the indicators definition could represent even more the preferences of a specific group of participants.

Moreover, future studies remain necessary in terms of evaluating the applicability of the highest scoring WWTS alternative. Indeed, the genuine SDM structure also emphasizes the relevance of implementing, controling and learning about the alternative in order to make better decisions in the future.

Accessing data performances of WWTS related to seasonal and population sizes are certainly relevant parameters to consider whitin the stablishment of efficiencies. In this view, in order to have more reliable information and hence trustworthy results with the tools' application, those aspects should be contemplated.

Ultimately, this study was limited by the absence of performing the analysis of data from a pilot project. Instead, the performances were restricted to literature review. Despite the already cemented and thus reliable data concerning conventional WWTS alternatives in academic researches, specifically in regard to the EETS, it was not found solidified results in terms of all indicators' performances.

6.4.2 Related to the PS-WWTS alternatives

In future studies, three main factors related to the pre-selection of WWTS alternatives could be implemented. Firstly, management of gases and sludge. For that, it could be necessary to incorporate additional features in the tool and probably supplementary basic characteristics associated to the scenario subject of the analysis.

Secondly and in the same vein of the previous subproducts mitigation, it would be interesting not only to manage them, but also to assess the reusability of them within the treatment and their generation.

Finally, an adaptation within the excel file code that might establish a feature to facilitate for the manager the creation of a specific XML format file to be afterwards associated with the evaluation tool. The ValueCharts tool already have a component that generates a decision context directly from loading a specific XML file.

6.4.3 Related to the ValueCharts Tool

Given that the tool is a free web tool, one of the important suggestions by the ValueCharts tool application is the potentiability of also using it in other approaches, with different alternatives, indicators and groups of people.

For instance, the quantity and characteristics of those factors are variable, and it depends only on the objectives of the manager. Clearly, the same logic is valid for alternatives and groups of people, where, if applied in other scenarios, different aspects should be considered to define the variables of the decision concepts.

Nevetheless, even for this research and the scenario presented, some characteristics related to indicators could be more deeply exploited. For example, those related to acknowledged levels of sustainability of those systems. Giving examples, it could encompass the reuse of subproducts of the treatment such as gases for cooking, water heating, sludge disinfection, and others. Another aspect being researched about the reuse of subproducts is related to solids recycling, especially related to nutrients such as phosphorus and struvite in agriculture and fertilization.

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APPENDICES

APPENDIX 1 – QUESTIONNAIRES

APPENDIX 1.A – QUESTIONNAIRE

This survey is part of a research study on Decision Making Analysis (DMA) with respect to developing a support decision making methodology for helping the definition of different Wastewater Treatment System (WWTS) alternatives in a given scenario.

We emphasize that the responses will be used only for study purposes. The main objective here is to collect information regarding the indicators and preferences of the participants and also evaluate the applied tools.

This inquiry is supposed to take around only 15 minutes. If you have any question, you can contact me (Danilo Strapasson) by e-mail at danilo.strapasson@gmail.com. Please return the fulfilled questionnaire to me in the stamped addressed envelope provided, or by e-mail.

CONFIDENTIALITY

I undertake not to share any private information. Your answer to this questionnaire will be used for the sole purpose of develop a structured methodology to support the participants to define the best solution of available WWTS alternatives. After I have collected the answers and the research is finished, the data will be held safely and the personal information will be deleted.

This research is being developed by Danilo Cesar Strapasson as part of graduate degree, under the supervision of Professors Daniel C. dos Santos (from UFPR - Brazil), Gunilla Öberg and Eric R. Hall (both from UBC – Canada). Once your participation is entirely voluntary, we will assume that you consent your answers to be used as part of my research.

If you consider yourself a participant, for the following questions imagine you are required to solve a problem of providing WWTS for a peri-urban scenario (São José Community – Colombo/PR), where there are not proper sanitation services. Now please begin the survey.

SECTION A (BACKGROUND/PERSONAL INFORMATION)

Name (same as ValueCharts): ______________________________

A.1) What is your position:	
Research specialist (e.g. environmental approaches, water treatment, wastewater treatment, water quality, etc.)	☐
Employee of a company which provides wastewater treatment infrastructure	☐
Member of the committee leadership community	☐
Member of the community	☐
Member of the watershed committee	☐
Government official	☐
Donor agencies	☐
Investment companies	☐
Other:	

A.2) Did you have a briefing explanation about the concept of this decision analysis?	☐ **Yes**	☐ **No**
If the answer is "Yes", did you fell the explanation:	☐ Sufficient ☐ Insufficient	

A.3) Given your position, do you fell your opinion relevant to participate as a member of the decision making process regarding WWTS?	☐ **Yes**	☐ **No**

A.4) Do you feel necessity of planning sanitation infrastructure solutions for the aimed community of this study?	☐ **Yes**	☐ **No**

A.5) Have you ever participated in a decision making analysis regarding water governance for a city/community	☐ **Yes**	☐ **No**
If the answer is "Yes", please briefly specify the process below:		

A.6) Do you use, or have used, any tool as part of the decision making process to define WWTS alternatives?			☐ **Yes**	☐ **No**
If the answer is "Yes", which tool:				
If "Yes", what is your opinion regarding the utility of this/these tool(s)?	Poor	Ok	Excellent	I do not know
	☐	☐	☐	☐

If "Yes", does this/these tool(s) consider any of the following group of indicators?	Environmental	Social	Economic	Other:	I do not know
	☐	☐	☐	☐	☐

A.7) Even if you have not used, do you know any other tool with this purpose?			**☐ Yes**		**☐ No**
If the answer is "Yes", please specify the name of the tool:					
If "Yes", what is your opinion regarding the utility of this/these tool(s)	Poor	Ok	Excellent		I do not know
	☐	☐	☐		☐
If "Yes", does this/these tool(s) consider any of the group of indicators as follow?	Environmental	Social	Economic	Other:	I do not know
	☐	☐	☐	☐	☐
Is there any other tool that you might know?					
What is your opinion regarding the utility of this/these tool(s):	Poor	Ok	Excellent		I do not know
	☐	☐	☐		☐
If "Yes", does this/these tool(s) consider any of the group of indicators as follow?	Environmental	Social	Economic	Other:	I do not know
	☐	☐	☐	☐	☐
Please list below other tools that you might know:					
What is your opinion regarding the utility of this/these tool(s):	Poor	Ok	Excellent		I do not know
Tool`s name:	☐	☐	☐		☐
Group of indicators:					
Tool`s name:	☐	☐	☐		☐
Group of indicators:					
Tool`s name:	☐	☐	☐		☐
Group of indicators:					

A.8) Considering the availability of open-free computer tools, such as the "Pre-selection (PS-WWTS)" or "ValueCharts", to select WWTS alternatives for a city / community / household, would you be willing to use it?		
PS-WWTS	☐ Yes	☐ No
ValueCharts	☐ Yes	☐ No

A.9) Considering an existing constitutional right of having adequate sanitation by simply paying taxes for or the aimed community of this study, are you willing to provide help to construct and/or operate a WWTS for the community of the study case?	☐Yes	☐No		
If the answer is "Yes", in which way:				
Manpower building ☐	Manpower operating ☐	Paying ☐	Designing ☐	Securitizing ☐
Other:				

SECTION B (TECHNICAL INFORMATION)

This section intends to collect the opinion of several criteria and indicators widely used in the field of decision making and specifically selecting Wastewater Treatment System (WWTS) alternatives

B.1) The Pre-Selection tool subject

B.1.1) How much do you agree with the following variables to pre-select a WWTS alternatives? (CHOOSE ONE BOX IN EACH ROW)	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I do not know**
Application level (City, Community and Household)	☐	☐	☐	☐	☐	☐
Urban characteristics (Rural, Peri-urban and Densely-populated areas)	☐	☐	☐	☐	☐	☐
Input loads (High, Medium and Low strength wastewater)	☐	☐	☐	☐	☐	☐

B.1.2) Do you think that a limited number of variables is important for pre-selecting WWTS alternatives?			☐ **Yes**	☐ **No**
If the answer is "Yes", how many:				
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

B.1.3) Do you know any other relevant variable you feel that should be on the "Pre-selection" tool as a pre-selection criterion?	☐ **Yes**	☐ **No**
If the answer is "Yes", please specify the variables above:		

B.1.4) How much do you agree with the following devices of each stage of the treatment process? (CHOOSE ONE BOX IN EACH ROW)	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I do not know**
Preliminaries	☐	☐	☐	☐	☐	☐
Please mention other devices:						
Primaries	☐	☐	☐	☐	☐	☐
Please mention other devices:						
Secondaries and Post-Secondaries	☐	☐	☐	☐	☐	☐
Please mention other devices:						
Tertiaries	☐	☐	☐	☐	☐	☐
Please mention other devices:						

B.1.5) After defining the variables and based on the WWTS alternatives suggested on the tool, how do you pre-select WWTS to input on the ValueCharts tool? (CHOOSE ONE BOX IN EACH ROW)	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I do not know**
Technical criteria	☐	☐	☐	☐	☐	☐
Representativeness criteria	☐	☐	☐	☐	☐	☐
Another (other) that you strongly agree: ______________________________________						

B.2) The ValueCharts tool subject

B.2.1) How much do you agree/disagree with the following indicators, regarding the environmental criteria, that should be on the tool to select a WWTS alternative? (CHOOSE ONE BOX IN EACH ROW)	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I do not know**
Organic matter removal						
BOD[A] removal efficiency of the WWTS	☐	☐	☐	☐	☐	☐
COD[B] removal efficiency of the WWTS	☐	☐	☐	☐	☐	☐
Nutrients Removal						
N[C] removal efficiency of the WWTS	☐	☐	☐	☐	☐	☐
P[D] removal efficiency of the WWTS	☐	☐	☐	☐	☐	☐
Solids Removals						
TSS[E] removal efficiency of the WWTS	☐	☐	☐	☐	☐	☐
TS[F] removal efficiency of the WWTS	☐	☐	☐	☐	☐	☐
Pathogens removal – Fecal coliforms	☐	☐	☐	☐	☐	☐
GHG[G] emissions from the WWTS (CO_2, CH_4, etc.)	☐	☐	☐	☐	☐	☐
Operational temperatures	☐	☐	☐	☐	☐	☐

Land requirements	☐	☐	☐	☐	☐	☐
Chemicals consumption for the treatment	☐	☐	☐	☐	☐	☐
Availability of material and components	☐	☐	☐	☐	☐	☐
Resources recovery and/or reuse (solid, liquid and gas components)	☐	☐	☐	☐	☐	☐
Production of sludge	☐	☐	☐	☐	☐	☐
Acidification	☐	☐	☐	☐	☐	☐
Environmental benefits	☐	☐	☐	☐	☐	☐
Availability of power source	☐	☐	☐	☐	☐	☐
Energy consumption in the treatment process	☐	☐	☐	☐	☐	☐
Topography	☐	☐	☐	☐	☐	☐
Amount of Rainfall	☐	☐	☐	☐	☐	☐
Promotion of sustainable behavior	☐	☐	☐	☐	☐	☐
Recovery of phosphate	☐	☐	☐	☐	☐	☐
Abiotic depletion	☐	☐	☐	☐	☐	☐
Residuals management	☐	☐	☐	☐	☐	☐
Water reuse	☐	☐	☐	☐	☐	☐
Heavy metals removal	☐	☐	☐	☐	☐	☐
pH	☐	☐	☐	☐	☐	☐
Conductivity	☐	☐	☐	☐	☐	☐
Alkalinity	☐	☐	☐	☐	☐	☐
Groundwater preservation	☐	☐	☐	☐	☐	☐
Available area to expand the WWTS	☐	☐	☐	☐	☐	☐

[A]Biological Oxygen Demand [C]Nitrogen [E]Total Suspended Solids [G]Grenhouse Gases
[B]Chemical Oxygen Demand [D]Phosphurus [F]Total Solids

B.2.2) Do you know any other relevant indicator related to the <u>environmental</u> criteria you feel that should be on the tool? ☐ **Yes** ☐ **No**

If the answer is "Yes", please specify above:

B.2.3) Do you think that a limited number of indicators is important for selecting the most suitable WWTS alternative? ☐ **Yes** ☐ **No**

If the answer is "Yes", how many:

1-5 ☐	5-10 ☐	11-15 ☐	16-20 ☐	21 or more ☐

B.2.4) How much do you agree/disagree with the following indicators, regarding the <u>social</u> criteria, that should be on the tool to select a WWTS alternative? (CHOOSE ONE BOX IN EACH ROW)	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I do not know**
Acceptance	☐	☐	☐	☐	☐	☐
Staffing requirements to operate the WWTS	☐	☐	☐	☐	☐	☐
Community size served	☐	☐	☐	☐	☐	☐
Local waterborne diseases (hepatitis, cholera, etc.)	☐	☐	☐	☐	☐	☐
Participation of the community in building and operation	☐	☐	☐	☐	☐	☐
Odor potential	☐	☐	☐	☐	☐	☐
Availability of nearby professional skills	☐	☐	☐	☐	☐	☐
Population density	☐	☐	☐	☐	☐	☐
Endemic vector-borne diseases (yellow fever, malaria, etc.)	☐	☐	☐	☐	☐	☐
Population growth	☐	☐	☐	☐	☐	☐
Population size	☐	☐	☐	☐	☐	☐

B.2.5) Do you know any other relevant indicator related to <u>social</u> criteria, that you "strongly agree" which should be on the tool?	☐ **Yes**	☐ **No**
If the answer is "Yes", please specify below:		

B.2.6) How much do you agree with the indicators regarding the <u>economic</u> criteria, to select a WWTS addressed to the nearby community? (CHOOSE ONE BOX IN EACH ROW)	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**I do not know**
Operational and Maintenance (O&M) costs	☐	☐	☐	☐	☐	☐
Capital costs	☐	☐	☐	☐	☐	☐
User costs	☐	☐	☐	☐	☐	☐
Land costs	☐	☐	☐	☐	☐	☐
Availability of funds	☐	☐	☐	☐	☐	☐

B.2.7) Do you know any other relevant indicator related to the <u>economic</u> criteria that you "strongly agree" which should be on the tool?	☐ **Yes**	☐ **No**
If the answer is "Yes", please specify below:		

B.2.8) Do you know any other relevant indicator that you "strongly agree" which should be on the tool?	☐ **Yes**	☐ **No**
If the answer is "Yes", please specify below:		

SECTION C (TOOLS' ANALYSIS)

C.1) The PS-WWTS tool subject

C.1.1) How do you evaluate the tool in terms of the following criteria, related to the usability?	Strongly unsatisfactory	unsatisfactory	Neutral	satisfactory	Strongly satisfactory	I do not know
Visualization	☐	☐	☐	☐	☐	☐
Interface	☐	☐	☐	☐	☒	☐

C.1.2) How do you evaluate the explanation given by the applier regarding how to use the tool?	Strongly unsatisfactory	unsatisfactory	Neutral	satisfactory	Strongly satisfactory	I do not know
	☐	☐	☐	☐	☐	☐

C.1.3) Do you have any suggestion or modification regarding any aspect of the tool (e.g. usability, layout, features, visualization, user interface, etc.)?	☐ Yes	☐ No
If the answer is "Yes", please specify below:		

C.2) The ValueCharts tool subject

C.2.1) How do you evaluate the tool in terms of the following criteria, related to the usability?	Strongly unsatisfactory	unsatisfactory	Neutral	satisfactory	Strongly satisfactory	I do not know
Visualization	☐	☐	☐	☐	☐	☐
Interface	☐	☐	☐	☐	☐	☐

C.2.2) How do you evaluate the explanation given by the applier regarding how to use the tool?	**Strongly unsatisfactory**	**unsatisfactory**	**Neutral**	**satisfactory**	**Strongly satisfactory**	**I do not know**
	☐	☐	☐	☐	☐	☐

C.2.3) After the first result obtained, were you aware that you could change your given preferences only by sliding the charts?	☐ Yes	☐ No

How do you evaluate this "trade-off" feature?	Strongly unsatisfactory	unsatisfactory	Neutral	satisfactory	Strongly satisfactory	I do not know
	☐	☐	☐	☐	☐	☐

C.2.4) Do you have any suggestion or modification regarding any aspect of the tool (e.g. usability, layout, features, visualization, user interface, etc.)?	☐ Yes	☐ No
If the answer is "Yes", please specify below:		

APPENDIX 1.B – INTERVIEW

SECTION A (BACKGROUND/PERSONAL PERCEPTIONS)

Name:____

A.1) How many years have you studied?				
0 ☐	1-3 ☐	4-6 ☐	7-9 ☐	10 or more ☐

A.2) How old are you?				
10-20 ☐	11-20 ☐	21-30 ☐	31-40 ☐	40 or more ☐

A.3) How many persons are there in your household?				
1 ☐	2 ☐	3 ☐	4 ☐	_ ☐

A.4) Do you feel necessity of planning WWT infrastructure for your community?	☐ Yes	☐ No

A.5) Considering an existing constitutional right of having adequate sanitation by simply paying taxes, are you willing to provide help to construct and/or operate a WWTS for your community of the study case?			☐ Yes	☐ No
If the answer is "Yes", in which way:				
Manpower building ☐	Manpower operating ☐	Paying ☐	Designing ☐	Securitizing ☐
Other:				

SECTION B (TECHNICAL INFORMATION)

This section intends to collect information of the decision content and preferences of several indicators to be inputted at the ValueCharts by the manager of the decision making analysis

B.1) Do you agree to have a WWTS in nearby areas of your community?	☐ Yes	☐ No

B.2) ValueCharts Inputs

B.2.1) Environmental Aspects

a) How much do you agree with the following variables? (FOR EACH ROW, USING THE SCALE OF 1 to 10*) * It must be defined at least a 1 and a 10 for each indicator)	**0% to 75% of removal - Unsatisfactory**	**76% to 88% of removal - Acceptable**	**89 to 100% of removal - High**
Good removal of components that consume O_2 (it creates an inadequate environment for fish and plants, and also causes pollution)	__	__	__
Good removal of components that induce growth of hazardous surface algae (it creates an inadequate environment for fish and plants, and also causes pollution)	__	__	__
Good removal of components that induce turbidity and anaerobic conditions (it creates an inadequate environment for fish and plants, and also causes pollution)	__	__	__
Good removal of components that cause bacterial infectious diseases	__	__	__
	Strongly disagree	**Neutral**	**Strongly agree**
Compact systems instead of large area requirements	__	__	__
No elevated external energy sources demand	__	__	__

b) Do you know any other relevant environment variable you feel that should be important?	☐ **Yes**	☐ **No**
If the answer is "Yes", please specify the variables bellow:		
Clique ou toque aqui para inserir o texto.		
Clique ou toque aqui para inserir o texto.		

B.2.2) Economic Aspects

a) How much do you agree with the following variables? (FOR EACH ROW, USING THE SCALE OF 1 to 10*) * It must be defined at least a 1 and a 10 for each indicator)	**Strongly disagree**	**Neutral**	**Strongly agree**
Low costs for implementation instead of expensive WWTS constructions	__	__	__
Low costs maintenance/operation instead of expensive monthly WWTS	__	__	__

b) Do you know any other relevant economic variable you feel important?	☐ **Yes**	☐ **No**
If the answer is "Yes", please specify the variables bellow:		
Clique ou toque aqui para inserir o texto.		
Clique ou toque aqui para inserir o texto.		

B.2.3) Social Aspects

a) How much do you agree with the following variables? (FOR EACH ROW, USING THE SCALE OF 1 to 10*) * It must be defined at least a 1 and a 10 for each indicator)	Strongly disagree	Neutral	Strongly agree
Lower number of staff in systems in comparison to WWTS which needs high amounts of employees	__	__	__
	Low	Moderate	High
Odor potential by possible nearby WWTS	__	__	__

b) Do you know any other social relevant variable you feel important?	☐ Yes	☐ No
If the answer is "Yes", please specify the variables bellow:		
Clique ou toque aqui para inserir o texto.		
Clique ou toque aqui para inserir o texto.		

a) How do you weight the variables according to your preferences, from the objective that you would most prefer to the least?	Weights (1 – 11)
1 – Organic matter removal	__
2 – Nutrients removal - N	__
3 – Nutrients removal - P	__
4 – Total solids removal	__
5 – Pathogens removal	__
6 – Land requirements	__
7 – Consumption of electricity	__
8 – Capital costs	__
9 – Operational & Maintenance (O&M) expenses	__
10 – Staffing requirements to operate a WWTS	__
11 – Odor generation	__

SECTION C (FINAL QUESTIONS)

C.1) Did you have a briefing explanation about the intention of this interview and the concept of this decision analysis?	☐ Yes	☐ No
If the answer is "Yes", did you fell the explanation:	☐ Sufficient ☐ Insufficient	

C.2) Have you ever participated in an interview in order to define a basic infrastructure for your community?	☐ Yes	☐ No

C.3) As a member of the community, do you fell your opinion relevant to participate as a member of the decision making process regarding WWTS?	☐ Yes	☐ No

APPENDIX 2 – PS-WWTS INTERNAL INFO

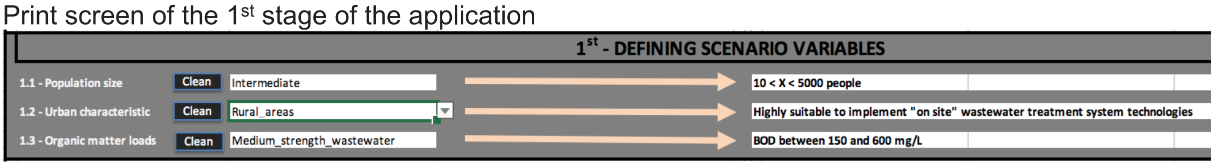
A) 1st stage of the PS-WWTS tool

Application level	Description	References
City	X > than 5000 people	
Community	10 < X < 5000 people	Ho and Anda (2006)
Household	X < 10 people	

Urban characteristics	Description	References
Rural areas	Highly suitable to implement "on site" wastewater treatment system technologies	Nogueira et al. (2009)
Peri-urban areas	Limited possibilities for "on site", but highly suitable for decentralized wastewater treatment system technologies	Ho and Anda (2006)
Densely populated areas	There is no space for "on site" and limited possibilities for decentralized wastewater treatment system technologies	Paterson et al. (2007)

Sewage level	Description	References
Low strength wastewater	COD lower than 300 mg/L	MetCalf and Eddy (2014)
Medium strength wastewater	COD between 300 and 1200 mg/L	MetCalf and Eddy (2014)
High strength wastewater	COD higher than 1200 mg/L	MetCalf and Eddy (2014)

Print screen of the 1st stage of the application

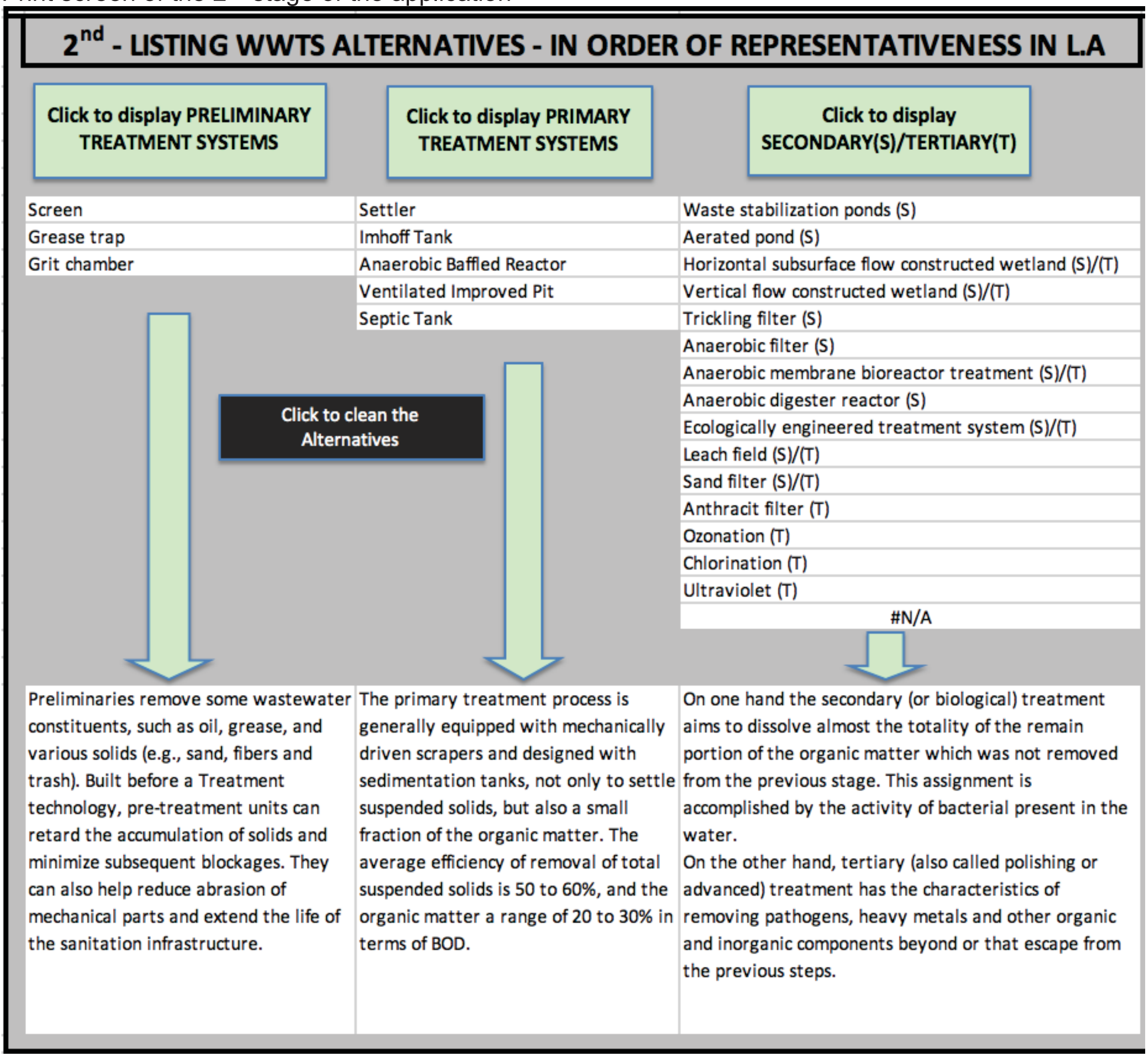


B) 2nd stage of the PS-WWTS tool

Phase of the Treatment	Description	References
Preliminary	Preliminaries remove some wastewater constituents, such as oil, grease, and various solids (e.g., sand, fibers and trash). Built before a Treatment technology, pre-treatment units can retard the accumulation of solids and minimize subsequent blockages. They can also help reduce abrasion of mechanical parts and extend the life of the sanitation infrastructure.	von Sperling and Chernicharo (2005); MetCalf and Eddy (2014)
Primary	The primary treatment process is generally equipped with mechanically driven scrapers and designed with sedimentation tanks, not only to settle suspended solids, but also a small fraction of the organic matter. The average efficiency of removal of total suspended solids is 50 to 60%, and the organic matter a range of 20 to 30% in terms of BOD.	von Sperling and Chernicharo (2005); WBG (2016)

Secondary / Post-secondary	Secondary (or biological) treatment aims to dissolve almost the totality of the remain portion of the organic matter which was not removed from the previous stage. This assignment is accomplished by the activity of bacterial present in the water.	von Sperling and Chernicharo (2005); WBG (2016)
Tertiary	Tertiary (also called polishing or advanced) treatment has the characteristics of removing pathogens, heavy metals and other organic and inorganic components beyond or that escape from the previous steps.	von Sperling and Chernicharo (2005); WBG (2016)

Print screen of the 2nd stage of the application



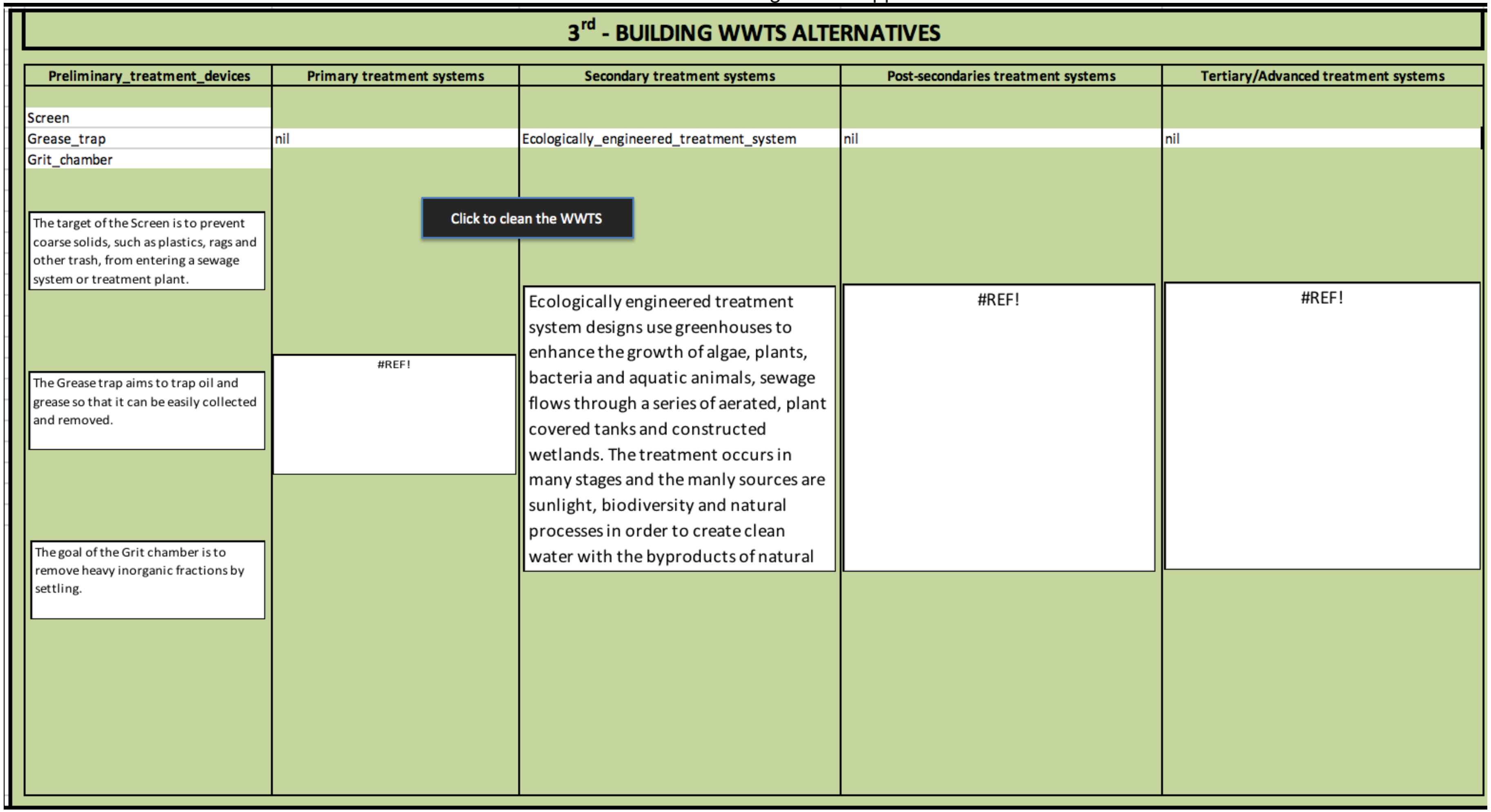
C) 3rd stage of the PS-WWTS tool

Wastewater Treatment System	Description	References
	Preliminary Treatment	
Screen	The target of the Screen is to prevent coarse solids, such as plastics, rags and other trash, from entering a sewage system or treatment plant.	Tilley *et al* (2014)
Grit chamber	The goal of the Grit chamber is to remove heavy inorganic fractions by settling, usually with low hydraulic retention time.	von Sperling and Chernicharo (2005) and Tilley *et al* (2014)
Grease Trap	The Grease trap aims to trap oil and grease so that it can be easily collected and removed.	Tilley *et al* (2014)
	Primary Treatment	
Settler	A Settler is designed to remove suspended solids by sedimentation.	Tilley *et al* (2014)
Imhoff tank	The Imhoff tank is designed for solid-liquid separation and digestion of the settled sludge.	Tilley *et al* (2014)
Anaerobic baffled reactor	An Anaerobic baffled reactor is an improved Septic Tank with series of baffles under which the wastewater is forced to flow.	Tilley *et al* (2014)
Ventilated improved pit	Improved pits provide treatment by leaching and degradation. Continuous airflow through the ventilation pipe vents odors and acts as a trap for flies as they escape towards the light.	Tilley *et al* (2014)
Septic tank	Septic tanks are watertight chambers, through which blackwater and greywater flows for primary treatment. Settling and anaerobic processes reduce solids and organics, but the treatment is only moderate.	Tilley *et al* (2014)
	Secondary / Post-Secondary / Tertiary Treatment	
Anaerobic filter (Secondary)	An Anaerobic filter is a fixed-bed biological reactor with one or more filtration chambers in series. As wastewater flows through the filter, particles are trapped, and organic matter is degraded by the active biomass that is attached to the surface of the filter material.	Tilley *et al* (2014)
Biogas reactor (Secondary)	A Biogas reactor or anaerobic digester is an anaerobic treatment technology that produces (a) a digested slurry (digestate) that can be used as a fertilizer and (b) biogas that can be used for energy. Biogas is a mix of methane, carbon dioxide and other trace gases which can be converted to heat, electricity or light.	Tilley *et al* (2014)

Wastewater Treatment System	Description	References
Leach field (Secondary)	A Leach field, or drainage field, is a network of perforated pipes that are laid in underground gravel-filled trenches to dissipate the effluent from a water-based Collection and Storage/Treatment or (Semi-) Centralized Treatment technology.	Tilley *et al* (2014)
Activated sludge process (Secondary)	An Activated sludge process refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required.	Tilley *et al* (2014)
Waste stabilization ponds (Secondary)	Wastewater flows through a pond constructed for wastewater treatment, wherein it remains for many days. The soluble and fine particulate BOD is aerobically stabilised by bacteria which grow dispersed in the liquid medium, while the BOD in suspension tends to settle, being converted anaerobically by bacteria at the bottom of the pond. The required oxygen by the aerobic bacteria is supplied by algae through photosynthesis.	von Sperling and Chernicharo (2005); Tilley *et al* (2014)
Upflow anaerobic sludge blanket reactor (Secondary and Post-secondary)	The Upflow anaerobic sludge blanket reactor (UASB) is a single tank process. Wastewater enters the reactor from the bottom and flows upward. A suspended sludge blanket filters and treats the wastewater as the wastewater flows through it.	Tilley *et al* (2014)
Aerated pond (Secondary and Post-secondary)	An Aerated pond is a large, mixed, aerobic reactor. Mechanical aerators provide oxygen and keep the aerobic organisms suspended and mixed with water to achieve a high rate of organic degradation.	Tilley *et al* (2014)
Trickling filter (Secondary and Post-secondary)	A Trickling filter is a fixed-bed, biological reactor that operates under (mostly) aerobic conditions.	Tilley *et al* (2014)
Anaerobic membrane bioreactor treatment (Secondary and Post-secondary)	The role of the membrane within the Anaerobic membrane bioreactor (AnMBR) is to serve as a selective barrier and therefore to block the passage of certain constituents. Its strong separation ability can make the SS turbidity near to be zero.	Metcalf & Eddy (2014)
Horizontal subsurface flow constructed wetland (Secondary, Post-secondary and Tertiary)	A Horizontal subsurface flow constructed wetland is a large gravel and sand-filled basin where wastewater flows horizontally through the basin. The filter material filters out particles and microorganisms degrade the organics.	Tilley *et al* (2014)

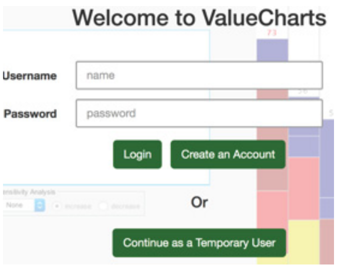
Wastewater Treatment System	Description	References
Vertical flow constructed wetland (Secondary, Post-secondary and Tertiary)	A Vertical flow constructed wetland is a planted filter where wastewater flows vertically down through the filter matrix to the bottom of the basin where it is collected in a drainage pipe.	Tilley *et al* (2014)
Ecologically engineered treatment system (Secondary, Post-secondary and Tertiary)	Ecologically engineered treatment system designs use greenhouses to enhance the growth of algae, plants, bacteria and aquatic animals, sewage flows through a series of aerated, plant covered tanks and constructed wetlands. The treatment occurs in many stages and the main sources are sunlight, biodiversity and natural processes in order to create clean water with the by-products of natural gases and biological material.	(Teal, 1993)
Sand filter	The Sand filter can remove pathogens, residual suspended solids and/or dissolved constituents. The filter bed usually includes two or more equal sized cells, independently operated.	Tilley *et al* (2014)
Aerobic maturation polishing pond	An aerobic/maturation/polishing pond provides the final level of treatment, it is shallow ensuring that sunlight penetrates the full depth for photosynthesis to occur.	Tilley *et al* (2014)
Ozonation	The destruction, inactivation, or removal of pathogenic microorganisms can be achieved by ozonation. Ozone is a powerful oxidant and is generated from oxygen in an energy-intensive process, degrading both organic and inorganic pollutants, including odor-producing agents.	Tilley *et al* (2014)
Chlorination	The destruction, inactivation, or removal of pathogenic microorganisms can be achieved by chemical means such as chlorine which oxidizes organic matters.	Tilley *et al* (2014)
Ultraviolet	The destruction, inactivation, or removal of pathogenic microorganisms can be achieved by UV radiation generated through special lamps that can be installed in a channel or pipe.	Tilley *et al* (2014)
Anthracite filter	Activated carbon absorbers not only remove a variety of organic and inorganic compounds, but they also eliminate taste and odor.	Tilley *et al* (2014)

Print screen of the 3rd stage of the application



APPENDIX 3 – VALUECHARTS TOOL'S SCREENS

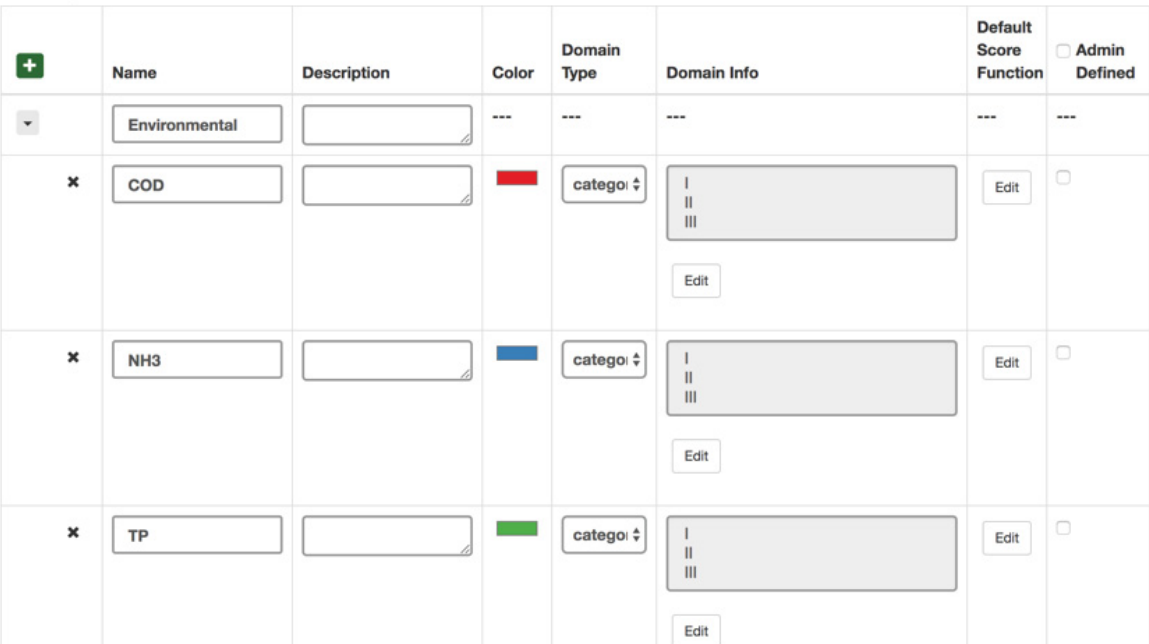
A) User account (1) and Evaluation analysis' names creation (2)



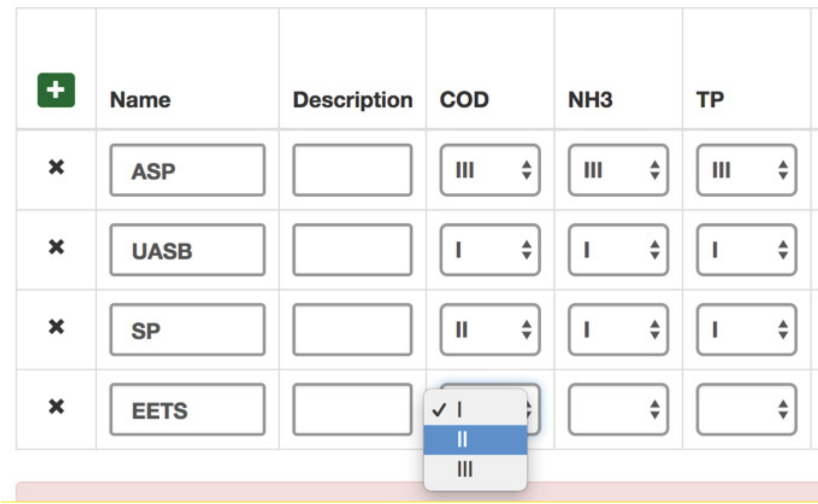
1)

2)

B) Inputs of the Indicators'set criteria Types



C) Inputs of the Alternatives'set and Data Associated



D) Defining Scores Function

E) Setting Priorities

Objective	Worst Outcome	Best Outcome
COD	I	III
NH3	I	III
TP	I	III
Fecal_Coliforms	II	III
TSS	I	II
Land_Requirements	0.375 m2/m3	41.25 m2/m3
Energy_Consumption	0 kWh/m3	39.5 kWh/m3
Capital_Costs	69 $/m3	450 $/m3
OM_Costs	0.02 $/m3	1.8 $/m3
Odor_Removal	High	Low
Staffing_Requirements	0.002 p.e/m3	0.002 p.e/m3

F) Example of a Result Chart